THE EFFECT OF ACTIVITY-BASED COSTING ON TRADITIONAL OPERATIONS RESEARCH MODELS

By

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I dedicate this work to my husband, Jim, who kept me going through this long journey,
to my daughters, Alix and Kris, who bring joy and laughter to every day,
and to my parents, Judith and Jaime, who inspired me by example.

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Activity-based Costing (ABC) was originally developed to improve product costing in complex manufacturing environments. The concepts of ABC have been extended to management through Activity-based Management (ABM) and are widely accepted in the management and accounting fields; however, little research has been done on the effects of this new accounting system on the operations research models traditionally used by industrial engineers. ABC is a valuable tool that not only eliminates product cost distortion, but can also provide important information about the manufacturing process.

The cost accounting system is used to allocate the costs of operation to departments, activities and products. Thus it provides the values for the parameters used in engineering decision models and can affect the results of these models. More importantly, the way in which costs are allocated defines the mathematical formulation of the objective function in these models. ABC methodology, with its emphasis on activities and non-volume-based cost drivers, can significantly change the assumptions made in decision models. This in turn can change the objective function and/or the structure of traditional operations research models.

We examine the effect of ABC on inventory lot size (economic order quantity), investment analysis, deterministic scheduling, project management (cost/schedule analysis) and production (product mix and break even analysis). In each case we seek to discover how industrial engineers can use the information provided by ABC to revise and improve these quantitative models. The primary objective is to show how the assumptions made by the accounting system are critical to the formulation of operations research models. Without this insight, the results predicted by these models may not be optimal and may not be validated by the financial results reported in the accounting system.

CHAPTER 1
INTRODUCTION

Activity-Based Costing

Over the past decade, many companies have revised their cost systems significantly as they reorganized to become more competitive in an environment that demands high quality, excellent service and reasonable prices (Mecimore and Bell, 1995). These new cost systems are founded on activity-based costing (ABC). Although activity-based costing was developed primarily to improve product costing, it can also provide valuable information about the manufacturing process. This is important to industrial engineers who work with these processes on a daily basis. While many industrial engineers might not feel that the cost accounting system is relevant to their work, the fact is that the cost accounting system provides the values for the parameters used in industrial engineering decision models. If the values are distorted or incorrect, then the decisions will be erroneous. In today's competitive environment, costing errors can lead to significant losses and it is imperative that management understand the true cost of doing business. ABC provides management with this information.

Cost accounting is concerned with the allocation of costs within the business environment. In manufacturing the focus is on the allocation of costs to products. This information is used by management in three ways: planning, reporting and controlling. In each case how costs are traced to products can significantly influence the outcome of decisions. For years organizations have operated under the assumption that cost information was accurate because it was precise, when in fact, many cost systems were providing misleading and inaccurate information.

Traditionally, materials, labor and manufacturing overhead are allocated to products based on the number of labor or machine hours or direct material dollars consumed. Although this simple, one-stage allocation scheme (from resources to products) can distort product cost, it made sense when it was first developed, since labor and materials often represented the majority of the manufacturing cost, while overhead was a small fraction of the cost. This was true in labor intensive manufacturing environments that produced a narrow range of products. Thus the effort and expense of collecting and processing data manually could hardly be justified to correct minor cost distortions.

Kaplan (1989) notes that traditional accounting control procedures stressed adherence to centrally determined standards, in accordance with the principles of scientific management. Extensive reports on the deviations of actual costs from the standards were prepared monthly, but the information used to prepare the standards and reports was crude, due to the expense of collecting data. Accounting systems allocated overhead based on data that was already being collected for other purposes: direct labor quantities as reported on payroll time cards and material usage as reported in purchase orders.

In the past 20 years many companies have experienced significant changes in their cost structure (Hardy and Hubbard, 1992). As the cost of the manufacturing process has increased, the relative importance of raw (direct) materials has decreased. At the same time, complex technology requires a complex support system and the cost of overhead, or indirect expense, has increased dramatically. For example, one leading semiconductor company had overhead costs that were 1400% of direct labor cost (Mangan, 1995). As a result, overhead has become the dominant cost component of many products. Traditional cost accounting has failed to properly address these changes, which can lead to significant distortions in product cost, particularly if the allocation base is unrelated to the actual consumption of resources. Activity-based Costing was developed to address this issue.

As early as 1963 Peter Drucker warned of the dangers of using traditional product costing to guide marketing decisions; however, costing products using activity-based costing was infeasible before the advent of modern computer technology and software. As the cost of information processing decreased and the capabilities of personal computers increased, companies began to experiment with new approaches to management accounting systems. During the 1970s and early 1980s companies such as Schrader Bellows, John Deere, Hewlett-Packard and Union Pacific used ABC to obtain better product cost information to guide them in pricing and product mix decisions. Robin Cooper formally defined the concepts and principles of activity-based costing in a series of articles in the late 1980s . Other authors, such as H. Thomas Johnson, Robert S. Kaplan and Peter B. B. Turney also made significant contributions.

Activity-based Costing, as the name suggests, traces costs to cost objects (products, customers, etc.) through activities. This is in contrast to traditional cost accounting which traces costs directly to products. Activities, rather than products, consume resources and the demand for those activities in the manufacturing process determines how the costs are allocated to the individual cost objects. Resources include all the costs recorded by the accounting system in carrying out daily business, such as salaries, materials and overhead (rent, utilities, insurance, advertising, etc.). Activities are procedures that are carried out in order to manufacture a product or provide a service. The business processes can be broken down into activities. Typically, activities are grouped by function and the grouping is referred to as an activity center. Cost objects are the final result of the business process.

The two-stage cost assignment from resources to activities and then from activities to cost objects is based on multiple cost drivers, such as number of setups, square footage of warehouse space, number of purchase orders, machine hours, number of parts, number of defects, etc. Cost drivers are the bases used to make cost assignments and can be resource drivers or activity drivers, depending on whether we are allocating resource costs to activities or activity costs to products, respectively. Cost drivers are selected to reflect the cause-and-effect relationships in the manufacturing process.[1] While traditional cost accounting allocates costs to products using volume cost drivers, ABC recognizes that costs may be driven by other factors, such as complexity.

Direct labor and materials can be allocated the same way under either traditional cost accounting or ABC, but overhead allocation is much more sophisticated under ABC, since it allows for multiple cost drivers. As a result, the ABC product costs can be radically different from those of the traditional cost accounting system. For example, traditional accounting will undercost a complex low volume product, subsidizing its cost by allocating most of the overhead to high-volume, standard products. The result can lead to incorrect decisions about product mix, pricing and process improvement. ABC is able to provide a more refined and "accurate" view of process costs thanks to the wide-spread use of computer technology in the manufacturing environment. This enables companies to economically compile the multiple cost driver information needed for the ABC system.

If we look at the allocation rates used in any cost accounting system (including ABC) we note that they are stated in terms of dollars per unit. The numerator is the cost of resources or activities (in dollars) and the denominator is some measure of how the resource or activity is consumed (for example, time, number of parts, dollars, etc.). In ABC, the denominators used to allocate resource dollars to activities are called resource drivers and those used to allocate activity dollars to products are called activity drivers. Figure 1-1 illustrates how ABC allocates costs to products (or cost objects).

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[1] Some authors limit the use of the term "cost driver" to the causal events that influence the quantity of work (see Raffish and Turney, 1991). We use it in a more general sense, refering to the mechanism of cost assignment (as most authors do) because causal events are very often used as the resource and activity drivers in the ABC system.

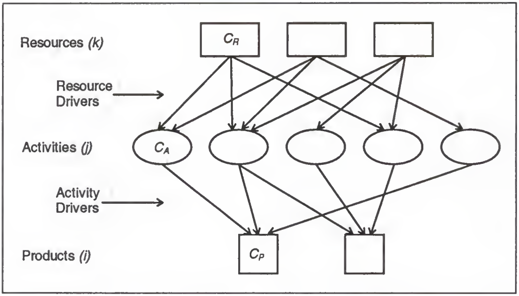

Figure 1-1. Activity-based Cost Allocation

Let the dollar amount of each resource cost pool k be C_{Rk}. Then the total cost of resources to be assigned to products (or any other cost objects) will be $\sum_k C_{Rk} = C$. The actual amounts are usually obtained from the accounting records, such as the general ledger, or the operating budget for each department. The first step is to assign the resource dollars in each department to the activities performed in that department. Each cost pool within the department will use a different resource driver or allocation base to distribute C_{Rk}. For example, if we want to allocate fuel costs, we might use number of gallons as our allocation base. Let r_{kj} be the amount of resource k driver (allocation base) consumed by activity j (the number of gallons consumed by each activity). Then the total allocation base for resource k is $\sum_j r_{kj} = r_k$ (the total number of gallons used by the department) and the allocation rate for resource k will be C_{Rk} / r_k (dollars/gallon). The dollar amount allocated from resource k to activity j is calculated as $C_{Rk}\left({}^{r_{kj}}\!/_{r_k} \right) = C_{Rkj}$.

We do this for all the resources to arrive at the cost of the activities. Thus each activity *j* has a total dollar cost of $\sum_{k=1}^{l} C_{Rkj} = C_{Aj}$.

Next we will allocate the cost of each activity to the products that demand that activity. Suppose the activity is material transfer, which includes fuel costs, as well as other resource costs. We might choose to allocate the costs of this activity based on the number of trips. Let a_{ji} be the amount of activity *j* driver (trips) consumed by product *i* (for simplicity, assume each trip can only accommodate one type of product). Then the total activity driver (total number of trips) for activity *j* is $\sum_i a_{ji} = a_j$ and the allocation rate for activity *j* is C_{Aj} / a_j (dollars/trip). The cost of activity *j* allocated to product *i* is calculated as $C_{Aj}\left({}^{a_{ji}}\!/_{a_j}\right) = C_{Aji}$ and the total cost of product *i* will be $\sum_j C_{Aji} = C_{Pi}$.

Note that it is possible (and often necessary) to allocate the cost of one or more activities to other activities rather than directly to products. This will be the case for support activities or departments such as maintenance or personnel. In this case the total cost of some activities would include not only C_{Rkj} dollars, but also some C_{Aji} dollars (where the cost of activity *j* had been allocated to activity *i*).

Example

The following is an example of how ABC can significantly change product costing. Suppose a company manufactures four products: A, B, C and D. The products differ in batch sizes (volume). Table 1-1 shows the resources used in one period (this example is limited to overhead resources, since direct materials and labor are assumed to be allocated directly to the product).

Table 1-1. Overhead costs

Benefits	Electricity	Supplies	Gasoline	Rent	Total
$ 3,000	$ 5,000	$ 1,000	$ 500	$ 3,000	$ 12,500

Table 1-2 shows the allocation of these resources directly to each product using a traditional cost accounting system based on machine hours.

Table 1-2. Traditional Overhead Allocation

Product	Volume	Mach hours	O/H rate	Allocation	Cost/Unit
A	10	5	$ 56.82	$ 284	$ 28.40
B	100	50	$ 56.82	$ 2,841	$ 28.40
C	10	15	$ 56.82	$ 852	$ 85.20
D	100	150	$ 56.82	$ 8,523	$ 85.20
Total		220		$ 12,500	

Suppose that four activities consume the resources: transporting parts to and from the machines, setting up the machines, machining the parts and administration. Table 1-3 shows the resource drivers and Table 1-4 shows how the overhead is allocated to each of these activities. In Table 1-5 we show the activity drivers and Table 1-6 shows how the costs of the activities are allocated to each of the products. Note the significant differences in the cost per unit of products A and C. Such changes in product cost are typical when an ABC system is implemented and a more accurate allocation of overhead is made.

Table 1-3. Resource Drivers

Resource	Driver	Transp	Setup	Mach	Adm	Total
Benefits	# of people	1	2	4	1	8
Electricity	Watts		100	800	100	1000
Supplies	Dollars		700		300	1000
Gasoline	Gallons	400				400
Rent	Sq. feet	100		1700	200	2000

Table 1-4. Allocation of Resources to Activities

Resource	Transp	Setup	Mach	Adm	Total
Benefits	375	750	1,500	375	3,000
Electricity		500	4,000	500	5,000
Supplies		700		300	1,000
Gasoline	500				500
Rent	150		2,550	300	3,000
Total ($)	1,025	1,950	8,050	1,475	12,500

Table 1-5. Activity Drivers

Activity	Driver	A	B	C	D	Total
Transportation	no. trips	3	2	5	10	20
Setup	no. setups	2	3	2	3	10
Machining	mach. hours	5	50	15	150	220
Administration	# of parts	2	2	3	3	10

Table 1-6. Allocation of Activities to Products

Product	Transp	Setup	Mach	Adm	Total	Cost/Unit
A	154	390	182	295	1,021	102.10
B	103	585	1,830	295	2,813	28.13
C	256	390	549	443	1,638	163.80
D	512	585	5,489	442	7,028	70.28
Total ($)	1,025	1,950	8,050	1,475	12,500	

This example serves to illustrate how low-volume (relative to machine hours) products such as A and C can be underpriced by the traditional cost accounting system. The ABC analysis showed that these products, although requiring relatively little machining, still needed a significant portion of the other activities. This could be the case if the product is very complex or requires special handling. The old accounting system was in essence subsidizing the low-volume products by allocating the overhead based on machine hours, when in fact, much of the overhead was independent of machine hours.

Decision Making with ABC

Although ABC was originally developed to improve product costing, its real strength lies in its analysis of the business process and the focus on activities required to manufacture the product or provide a service. This focus on activities has been extended to management in a philosophy known as activity-based management (ABM). The goal of ABM is continuous improvement and this is achieved by managing activities rather than departments or divisions. In developing an ABC model, management must first identify, analyze and understand the activities involved in the business process. This is the key to process improvement. ABM uses the information provided by ABC to identify value-added and non-value-added activities and to improve manufacturing processes and product design.

For industrial engineers, that means using ABC to improve our decision models. As we will see in this research, insights gained from ABC analysis can improve the results of traditional operations research models. Activity-based costing allows decision makers to accurately trace overhead and to determine the real causes of overhead. This information can be used to eliminate or improve activities that consume excessive amounts of overhead. ABC also highlights and quantifies the impact of design decisions on overhead costs, which can dramatically affect the final cost of products. Knowing this information ahead of time allows engineers to improve product and process design.

We will look at how ABC affects some of the traditional decision models used by industrial engineers to control and improve processes. We assume that the cost parameters used in these models are derived from accounting records. This is a very reasonable assumption since the alternative is to estimate the values without any consideration of the actual costs of manufacturing. Even if cost parameters are based on previous experience or benchmarking, the values are credible only if they were originally derived from the actual costs collected in the accounting system. Given this assumption, we will look at how ABC may change the value of these parameters and thus the results of the model. We will also see how the ABC methodology, with its emphasis on activities and non-volume-based cost drivers, may also change the model assumptions and therefore the objective function or the formulation.

As we examine a variety of operations research models, we will see that the underlying theme in each of the chapters is the fact that ABC makes it possible to build better models by providing accurate information about indirect costs. These costs have traditionally been treated by accountants as "fixed" with the cost accounting system spreading them out over products based on volume or some volume-related driver. The result has been not only inaccurate product cost information, but misleading decision models. This is because the decision models depend on the information provided by the cost accounting system. If accurate information about indirect costs is not available from the cost accounting system, then the decision models will also be lacking. In fact, most of the operations research models that we examined had this common flaw: indirect costs were treated as "fixed" and were either excluded completely from the model, or introduced in a very primitive fashion, assuming that they varied as a percentage of volume.

We will provide insight into how industrial engineers can use the information provided by ABC to improve and revise these models. The primary objective is to show how the assumptions made by the accounting system are critical to the outcome of the decision model and must therefore be considered by the industrial engineer in formulating these models. Moreover, if the assumptions made by the accounting system and the decision model are not the same, management may be frustrated in its efforts to improve the manufacturing process because the results predicted by the model may not be realized in the financial results reported by the accounting system and used to measure management performance.

CHAPTER 2
LITERATURE REVIEW

Development of ABC

The concept of activity-based costing has been prevalent in accounting journals since the late 1980s when it was first defined and popularized. Since then, hundreds of articles have been written on the subject, mostly in business journals, the majority of them being either of a descriptive nature or case studies. Relatively few articles have explored the implications of ABC on areas outside product costing and process improvement and even fewer have ventured outside the field of accounting to look at the affect of ABC on industrial engineering models.

In the 1960s, General Electric developed activity cost analysis in order to obtain better information for managing indirect costs. The technique traced each indirect activity in the company to one output of a particular department. The outputs caused other departments to engage in activities. The goal of the analysis was to determine the approximate percentage of time each employee spent on indirect activities and to trace the primary cause of each activity to the output of a department. However, GE did not extend this concept to product costing (General Electric, 1964).

In 1963 Peter Drucker warned of the dangers of using traditional product costing to guide marketing decisions and recognition of problems with traditional cost accounting grew during the 1970s. Driven by the availability of low-cost semiconductor technologies ABC began to appear in the late 1970s as a solution to product cost distortion. The idea of using cost drivers for product costing was initially implemented by consulting firms during the 1970s and early 1980s for companies such as Schrader Bellows, John Deere and Union Pacific to obtain better product cost information to guide them in pricing and mix decisions (Johnson, 1992). Berlant, Browning and Forster (1990) describe an activity-based system implemented at Hewlett-Packard based on an off-line accounting system developed by the manufacturing department.

In the early 1980s articles began to appear in the literature highlighting the problems with traditional product costing and formalizing the concepts of ABC. Miller and Vollman (1985) describe a "hidden factory" that incurs overhead costs that are not controlled by the cost accounting system. They suggested using drivers other than volume to allocate overhead. Brimson (1986) noted that most accounting systems did not provide the information necessary to manage automated manufacturing systems and Seed (1984) described changes needed in cost accounting systems in order to provide more reliable product cost information in advanced manufacturing environments.

In their book *Relevance Lost: The Rise and Fall of Management Accounting* (1987), Johnson and Kaplan called for major changes in the way organizations measure and manage costs. They noted that management accounting information is driven by the procedures and cycles of the organization's financial reporting system which makes it too aggregated and distorted to be relevant for planning and control decisions. They observed that financial accounting systems produce short-term profit pressures that can lead to a decrease in investment in the long-run. Monthly accounting statements can signal increased profits even when the long-term economic health of the firm has been compromised. They argued that new accounting systems were needed to take advantage of the reduced costs of collecting, processing, analyzing and reporting information brought about by the computing revolution. Computers used in automated factories can provide timely and relevant managerial information that can be used to develop more accurate, timely and effective reporting and controlling systems.

Cooper and Kaplan (1988a) discuss how product costs are distorted by the traditional cost accounting systems used by several manufacturing firms (the paper is based on information gained from studying more than 20 firms). They argue that marginal costing, long advocated by economists and accountants for product decisions, is rejected in practice because of the long-term commitments required to implement such decisions. However, the full cost information provided by traditional systems is not accurate and may also lead to incorrect decisions. They suggest that product costing must take into account the cost of complexity and transactions as well as volume. Robin Cooper formally defined the concepts and principles of activity-based costing in a series of articles titled "The Rise of Activity-Based Costing" in the late 1980s (1988a,b, 1989a,b). He identified diversity (in volume, size, complexity and other drivers) as the cause of bias in volume-based cost systems and developed a model to examine the relationship between the cost of measurement and accuracy in developing the optimal cost system and the factors affecting these parameters. He discussed factors that should be considered when designing an ABC system, including how many and what kind of cost drivers should be used based on sensitivity analysis. He also illustrated the concepts with five case studies.

Cooper and Kaplan (1988b) further illustrate the effect of ABC on product costing and discuss its value from a strategic point of view. Turney (1989, 1991) extends the concept of ABC to product design and continuous improvement and discusses how ABC can be used to create behavioral incentives and reduce cost. Cooper and Kaplan (1991) developed an activity hierarchy, arguing that certain expenses cannot be allocated at the unit level. They identified four levels of activities: facility-sustaining, product-sustaining, batch-level and unit-level. Turney (1992a) defines Activity-based Management (ABM) as using ABC information for continuous improvement and describes how ABC is linked to strategic choices. Kaplan (1992) describes the connection between ABC and ABM and Cooper and Kaplan (1992) discuss ways in which ABC information can be used to increase profits through resource and activity management. Mecimore and Bell (1995) describe the evolution of ABC from a product-costing focus to a process and business unit focus and eventually to a company-wide focus. Stratton (1993) argues that ABC should be extended to financial reporting.

Roth and Borthick (1989) describe an off-line ABC system designed to supplement the formal accounting system, which is how most companies implement ABC. They recognized some limitations to ABC, such as the inability to trace certain costs (due to practical limitations), the arbitrary choice of time periods in measuring product costs and the omission of costs related to marketing, advertising, R&D, warranties, etc. Hardy and Hubbard (1992) contrast traditional cost accounting with ABC, discussing the strengths and weaknesses of both systems, while Bonsack (1991) shows how standard costing and ABC are compatible.

Needy and Malzahn (1993) use simulation models to identify the conditions under which strategic decisions and resulting performance differed between traditional cost accounting and ABC. Babad and Balachandran (1993) provide an optimization model that balances savings in information processing costs with loss of accuracy. They show how to determine the number of drivers and identify the representative cost drivers. The model is formulated as an integer program.

Case Studies and Applications

In recent years numerous case studies have been published describing the implementation and impact of activity-based costing on organizations: O'Guin (1990), Harr (1990), Phillips and Collins (1990), Lee (1990), Jones (1991), Haedicke and Feil (1991), Pederson (1991), Brausch (1992), Plug (1992), Cooper et al. (1992), Rodgers, Comstock and Pritz (1993), Anderson (1993), McConville (1993), Mays and Sweeney (1994), Mangan (1995) and Bharara and Lee (1996). Cooper (1991) describes a seven-step plan for implementing activity-based costing systems and Sharman (1994) suggests a method to identify activities and drivers for ABC implementation. In 1993, the Institute of

Management Accountants issued a statement that provides an overview of the process of designing and implementing an ABC system.

Many authors have also written articles describing ABC and how it can be used in different areas of management: Sharman (1990), Drury (1990), Chaffman and Talbott (1991), Raffish (1991), Ray and Gupta (1992), Stevenson, Barnes and Stevenson (1993) and Tippett (1993). Beischel (1990) discusses process value analysis and ABC, while Yoshikawa, Innes and Mitchell (1994) relate functional analysis to ABC. Steimer (1990), Beheiry (1991) and Youde (1992) describe how ABC relates to the concept of quality and Turney (1989) examines the role of ABC in manufacturing excellence. Ochs and Bicheno (1991) link ABC to manufacturing strategy, while Kaplan (1989) argues that ABC can be used to better justify flexible manufacturing. Steen and Steensland (1994) suggest ABC as a tool for on-line profit monitoring in a process plant and Menzano (1991) shows how it can be used for information systems. Roth and Sims (1991) apply ABC to warehousing and distribution, Lewis (1991) applies it to marketing and Roehm, Critchfield and Castellano (1992) apply it to purchasing. Pirrong (1993) describes the use of ABC in service industries, Lawson (1994) studies the use of ABC in hospitals, Dhavale (1992) describes the use of ABC in cellular manufacturing systems and Zhuang and Burns (1992) develop a procedure to implement ABC in non-standard route manufacturing. Recently, the grocery industry has explored the link between ABC and Efficient Consumer Response (Haedicke, 1994, Valero, 1994 and Mathews, 1994).

Limitations of ABC

A number of authors have written about the limitations of ABC. For example, Johnson (1991) argues that although ABC overcomes distortions inherent in traditional financial cost accounting information, it does not necessarily help companies achieve continuous improvement. In his book *Relevance Regained: From Top-Down Control to*

Bottom-Up Empowerment (1992) he explains that activity analysis focuses attention on changing the amount of activity (or work) a company does for a given amount of revenue, but it does not focus people's attention on changing how work is done, nor does it link activity with customer satisfaction. Bakke and Hellberg (1991) feel that while ABC philosophy constitutes a necessary basis for long-term decisions about product mix, the information is not satisfactory for making short-term decisions. Tatikonda and Tatikonda (1991) note that simply allocating cost in a different way does nothing to control those costs. Roth and Borthick (1991) observe that ABC assumes that costs in each cost pool are driven by homogeneous activities and are strictly proportional to the activity. If either of these two assumptions are not met, ABC costs may also distort product costs.

The fact that ABC allocates both fixed and variable costs to activities and products makes it difficult to make certain economic decisions that depend on marginal costs based on a fixed production capacity. This shortcoming of ABC has been noted by several authors. Koehler (1991) argues that firms need direct costing and contribution approaches as well as ABC. He notes that ABC examples in the literature assume that a company has limited knowledge of the market price or the elasticity of demand and that ABC is not very useful for setting the price of a standard product for which there is a competitive market. Weisman (1991) argues that cost allocation systems, such as ABC, emphasize cost recovery rather than cost causality and are therefore incapable of providing managers with the information they need to make good business decisions. He suggests using only avoidable costs for cost/benefit analysis. Along the same lines, Sharp and Christensen (1991) claim that activity-based costs suffer a deficiency common to all full cost approximations: not all resources consumed by a cost object are avoidable in the absence of the particular object. They suggest that for managerial decision-making,activity-based costs need to incorporate the concept of attributable costs. Scott and Morrow (1991) make a similar observation, then show how ABC information can be modified to support make-or-buy decisions.

Woods (1992) notes that while ABC meets the concerns of manufacturing managers about the relevance of conventional cost data to the actual manufacturing process by assigning to each product the costs of all activities that are used in its manufacture, it does not allow for rational economic choices for most organizational levels because it mixes fixed and variable costs. He suggests that this information can be provided by an ABC system by giving managers a breakdown of the costs allocated to the activity and identifying those costs which can be controlled by the activity or department as variable and those that cannot be controlled as fixed, with the classification of costs as fixed or variable varying with the level of reporting. Christensen and Sharp (1993) suggest two refinements to ABC: categorizing activity costs into short-term variable, short-term fixed and committed fixed costs then determining the allocation rates for both categories of fixed costs based on the capacity provided through the incurrance of these costs.

Yang and Wu (1993) observe that product unit cost developed under ABC using historical data is often used to make pricing decisions without considering either the future price index (for variable cost) or capacity utilization (for fixed costs). Thus products are underpriced when unit variable cost is underestimated or overpriced when unit fixed cost is overestimated. They suggest using a "strategic" ABC unit cost, based on the capacity rate that the company wants the operation to achieve over its useful life or planning horizon. This enables the user to calculate a close approximation of the true long-term costs and to make better decisions about product mix, investments and staffing.

Operations Research Models

Economic Order Quantity

Johnson (1988) discusses how companies can use activity-based information to manage activities, not cost. He introduces the Economic Order Quantity (EOQ) problem and notes that it takes for granted the activities (setup and storage) whose costs are optimized by batch size. He explains how Toyota concentrated on reducing setup time which in turn reduces the EOQ quantity. Instead of managing setup cost, Toyota managed the cause of the setup cost, time. Hedge and Nagurajan (1992) recognize that setup cost has both a fixed and a variable component and they model the setup cost per setup as $a = m + Rt$, where t is the amount of time it takes for a setup, m is the setup costs independent of setup time (assumed to be constant from setup to setup) and R is the setup rate ($/unit time). Note that they still use number of setups as the cost driver, so the cost allocation ignores the effect of t. They speculate that an ABC analysis might reveal that setup costs are high, thus motivating the shop floor to reduce the number of setups in order to reduce costs, a strategy which they label as "short-term". On the other hand, they observe that the production engineers seek to reduce setup costs in the "long-term" by reducing setup times. They then combine these two goals in a time-constrained EOQ model.

Investment Analysis

Reeve (1989) observed that each activity is related to a product by way of a cost driver. The cost driver is a ratio whose numerator is the cost committed to the activity per time period and denominator is an estimate of the amount of activity driver used during the period. An investment can have an impact on an activity though either the numerator or the denominator. He notes that traditional justification techniques fail to consider the impact of process improvement efforts on complexity costs and he explains how ABC can reveal the cost impact of process changes. Ostrenga (1990) suggested that performance measures should represent a mix of financial and non-financial operating measures. He noted that performance measures can assist in process management by focusing on the significant activity levels and measuring the drivers of activities. Improvements in quality, throughput and other operational benefits may be difficult to quantify, but are real in terms of competitive posturing and should be included in investment management.

Brimson (1989) develops the concept of activity-based investment using an analysis of the activities that influence cost and quality in a modern manufacturing environment. Traditional investment analysis is based on the cash flow impact of each investment alternative, a process that does not take into account such important decision parameters as quality and efficiency. In addition, the traditional view compares investment alternatives proposed by individual department managers based on the benefits to each department, without analyzing the effect of the investment on the activities and goals of the company. He suggests that before comparing investment alternatives a company needs to identify the activities that support company goals. The investment analysis is then based on improving the performance of value-added activities and the elimination or minimization of non-value-added activities. The impact of an investment on the cost of these activities is determined through ABC analysis, which computes the estimated cost of each activity under a given investment alternative. Alternatives are also evaluated based on their impact on performance measures associated with each activity and a portfolio of investments is established for each key performance measure. The investments that both improve performance and meet or exceed a target return on investment (ROI) are the most desirable.

Sawhney (1991) developed a methodology for evaluating manufacturing investments that are heavily influenced by non-financial considerations. He suggested that investments should be evaluated in terms of the strategic objectives of the firm (in addition to the traditional financial analysis) and on their impact on production-related activities. The objective of the approach is to select investments that provide the greatest improvement to key activities as measured by critical success factors.

Analytical Hierarchy Process

Partovi (1991) proposes a model for evaluating the appropriateness of adopting ABC. It is based on the Analytic Hierarchy Process (AHP) developed by Saaty (1980). The model is in the form of a hierarchy that includes the two stages of ABC. The top half of the hierarchy corresponds to the first stage of ABC, where total overhead costs are allocated to the plant's major activities using resource drivers. The second half of the model allocates the cost of activities to products using activity drivers. The objective of the model is to allocate overhead costs to products. The author assumes that the values of the resource drivers are known and management need only determine their ratios for the AHP model. Pairwise comparisons are used to determining the relative importance of each activity to other activities with respect to a particular resource driver and the importance of the activity drivers relative to each activity. Similarly a set of pairwise comparisons evaluates the different products with respect to the activity drivers. The result of the model is an estimate of how ABC would allocate costs to products. If the allocations are significantly different from the values assigned by the current accounting system, the adoption of an ABC system is recommended.

Break-even Analysis

Metzger (1993) notes that ABC can improve the accuracy and relevance of multi-product break-even analysis. This is because ABC can more accurately trace cost to each product line. The traditional model only traces volume-based (variable) costs to each product, classifying all other costs as fixed. This model further assumes that all products contribute to fixed costs in proportion to their sales volume. The ABC model does not make this assumption. Instead, it traces non-volume-based (fixed) costs to each product line. These are costs that are fixed with respect to individual units, but vary from product to product. The break-even analysis can then be performed in terms of the variable costs vs. the traceable fixed costs assigned to each product.

Innes, Mitchell and Yoshikawa (1994, p. 13-15) point out the frailties of traditional break-even analysis. Costs and revenues rarely follow simple straight-line relationships and even if such approximations are adequate in the short term, extra capacity will eventually be required as output grows, causing fixed costs to follow a "step" pattern. In addition, product costs are influenced by factors such as complexity, flexibility, quality and service. Omitting these factors from the cost estimation model may lead to incorrect decisions.

Pricing and Product Mix

The use of ABC to forecast product cost and not just allocate historical costs is advocated by O'Guin (1992). He argues that ABC must be integrated into the MRP system in order to obtain valid unit costs for products. Malik and Sullivan (1995) develop a mixed integer programming model that utilizes activity-based costing information to determine optimal product mix and product cost in a multi-product manufacturing environment. They assume that the consumption of overhead resources is either in periodic steps or involves a one-time occurrence. By modeling indirect costs as step functions of volume they are able to incorporate the long-term variability of these costs.

Product Design

Emblemsvag and Bras (1994) develop an ABC model for use in the design of new products. The approach uses ABC methods to obtain reliable estimates of the costs of a design. The suitability of utilizing ABC in design is explored in the context of design for product retirement.

The Engineering Perspective

The articles relating ABC to engineering are relatively few. Butler (1994) discusses ABC and other accounting concepts from an engineering design and manufacturing perspective. Koons (1992) describes the role of the engineer in the implementation of an ABC system and Barnes (1991) notes that ABC is important to industrial engineers because it is closer to the systems IEs use in estimating and project justifications. The majority of the literature dealing with ABC has been limited to the accounting field, and, with the exception of the few articles mentioned above, little has been written about the effect of ABC on operations research models. For this reason, we feel it is important to explore this subject.

CHAPTER 3
ECONOMIC ORDER QUANTITY

Introduction

In the traditional inventory economic order quantity (EOQ) model, the total average cost of inventory is modeled as a function of the order quantity and depends on the cost per unit of the product, inventory carrying cost per unit (based on average inventory) and a fixed replenishment cost per order. In order to use this model we must agree on two conditions: first, that the model is a valid representation of the cost behavior of the inventory policy and second, that the values of the parameters used in the model are accurate. If we are to accept these conditions we must agree on how cost is to be measured; hence, we must agree on a cost accounting system. Because the cost accounting system records and allocates the cost of the inventory policy, the inventory model must reflect the assumptions made by the cost accounting system.

Consider the first condition. Suppose the accounting system allocates the cost of carrying inventory based on the amount of space allocated to each item, while the inventory model assumes that the cost of carrying inventory is based on the average value of the inventory. In this case, the model assumptions are flawed and the results of the model will not be validated by actual financial results. As for the second condition, regarding the accuracy of the cost parameters used in the model, there are several points to be made. First, the cost accounting system must record costs accurately. This is a basic requirement of any accounting system, whether traditional or ABC. Second, once the costs are recorded, they must be allocated to different departments or activities and eventually to the products, in order to obtain an accurate product cost. Not all accounting systems allocate costs in the same way and differences in allocation methods will result in different values for model parameters. The ABC system allocates costs based on the consumption of activities and allows a much greater variety of activity drivers (allocation bases) than the traditional cost accounting system, thereby resulting in a more realistic but more complex cost model.

In this chapter we will discuss the impact of ABC on the inventory economic order quantity model. In particular, we will look at what happens when an ABC analysis reveals that the "fixed" cost of placing each order varies with the total number of orders placed in a given time period. This might be the case, for example, if the accounting system uses the expenses assigned to the purchasing department to derive the cost per order used in the inventory model. In this case, the number of clerks in the department would likely represent the most significant portion of the department's expenses and it would make more sense to use the number of clerks (rather than a fixed cost per order) to determine the economic order quantity. Our approach is to incorporate long-term ABC cost drivers in a manner similar to that of Malik and Sullivan (1995). We model the cost of placing the order as a step function that depends on the number of clerks in the purchasing department. We then obtain an optimal solution for both the single-item and multiple-item cases. Next, we look at a model that combines both a fixed cost per order and an order cost per clerk. Finally, we examine a model that incorporates inventory cost as a step function of the number of warehouses, rather than the average cost of inventory.

The Inventory Model

The simplest type of inventory model involves a single item with a known static demand per period and an infinite planning horizon. There are no shortages allowed and replenishment is instantaneous. This model assumes that the average cost of the inventory policy is based on the cost per unit of the product (c), inventory carrying cost per unit inventory per unit time (h) and a fixed replenishment or setup cost (a). The average cost per unit of time can be written as

$$f(Q) = \frac{aD}{Q} + h\frac{Q}{2} + cD$$

where D is the demand per unit of time and Q is the order quantity or lot size. Thus the model seeks to find an optimal tradeoff between the number of orders or setups $(\frac{D}{Q})$ and the average inventory in stock $(\frac{Q}{2})$. The optimal order size is given by:

$$EOQ = \sqrt{\frac{2aD}{h}}$$

Looking at this from an ABC perspective, we see that there are two significant cost drivers: number of setups and average inventory in stock. The number of setups is the driver used to allocate the cost of the ordering or setup activity and average inventory in stock is the driver used to allocate the cost of the warehouse or holding activity. If the accounting system uses these cost drivers, then the cost of ordering or setup would be allocated to different products based on the number of setups required by each product line and the warehouse costs would be allocated based on the average inventory level of each product. This is important to note, as we will see later, because if the accounting system does not recognize the same cost drivers as the inventory model, the actual costs seen in the financial records may not support the decision made by the inventory model.

Before discussing the effect of ABC on this model, we must carefully examine the cost parameters, c, a and h. By definition, a is the fixed cost of placing an order or performing a setup. Every time we place an order, we will incur a cost a, regardless of the size, timing or type of order. Of course, this may not always be true. For example, Lee

(1986) examined the case where there is a freight cost associated with the order size in addition to a fixed cost.

Hedge and Nagurajan (1992) recognize that setup cost has both a fixed and a variable component and they model the setup cost per setup as $A = m + Rt$, where t is the amount of time it takes for a setup, m is the setup costs independent of setup time (assumed to be constant from setup to setup) and R is the setup rate ($/unit time). They speculate that an ABC analysis might reveal that setup costs are high, thus motivating the shop floor to reduce the number of setups in order to reduce costs, a strategy which they label as "short term". On the other hand, they observe that the production engineers seek to reduce setup costs in the "long term" by reducing setup times. This apparent conflict is due to the fact that the authors assume that the ABC cost allocation will continue to be based on the number of setups, while the engineering analysis implies that setup time and not number of setups, is the appropriate cost driver for setup costs. This highlights the importance of coordinating the ABC analysis and implementation with the manufacturing engineers. If setup time, t, is the significant cost driver and m is small, then the ABC system should reflect this by using setup time rather than number of setups to allocate costs. The shop floor will then be motivated to reduce setup time and will not be adversely impacted by an increase in the number of setups. If, on the other hand, m is large relative to Rt, then the engineers are working on the wrong cost driver, or two cost drivers should be used: number of setups for m and setup time for R. In any case, the total setup cost, A, will still be reduced if t is reduced, so that the increase in the number of setups (based on the EOQ model) will be offset by the reduced cost per setup and the shop floor will not be adversely impacted by the reduction in setup time. The bottom line is that the cost allocation should be based on the most significant cost drivers which should motivate the shop floor and the manufacturing engineers to reduce these cost drivers. Only if the engineers choose to ignore the most significant cost drivers will there appear to be a conflict between the cost system and the engineering analysis.

Porteus (1985) considered the cost of investing in reduced setup cost *a*. He assumed that the total setup cost varies with the number of setups as is done in the traditional EOQ model. He then examined the tradeoff between the investment costs needed to reduce the setup cost and the operating costs identified in the EOQ model. If we let $A = g(x) + a\frac{D}{Q}$, where *a* is the portion that remains constant from setup to setup and *g(x)* varies with some other cost driver, for example setup time, as suggested by Hedge and Nagarajan, then *A* is no longer a constant from setup to setup as assumed by Porteus. Instead, we have the following cost function:

$$f(Q,A) = \frac{Da}{Q} + g(x) + \frac{hQ}{2} + ik_A(a,b,x)$$

where *i* is the fractional cost of capital and $k_A(a)$ is the cost of reducing the setup cost to level *a*, given that we start at level a_0 (as suggested by Porteus). We now have the option of reducing the setup cost by either reducing the portion that is fixed from setup to setup or the portion that varies with some other cost driver *g(x)*. By identifying other cost drivers, the ABC system can, through cost allocation, help us decide which component to reduce and what the effect should be in the long run.

Often, *h* is expressed as *ic* where *i* is the fractional per unit time opportunity cost of capital and *c* is the cost per unit of inventory. This implies that we are not really concerned with the actual cost of carrying inventory (such as the warehouse rental or depreciation, the salary of warehouse personnel, inventory taxes, spoilage, utilities and insurance), but rather we are focusing on the fact that capital tied up in inventory does not produce income and is therefore undesirable. In reality, *i* may be adjusted upward to account for the actual holding costs as well as the cost of capital, but doing so assumes that these costs vary with the value of inventory, which may not be true. Alternatively, we may use $h' = ic + h$, where *ic* is the opportunity cost of capital and *h* represents the actual (or out-of-pocket) costs associated with carrying inventory. The total inventory holding costs are expressed as a function of Q.

Any cost accounting system, including ABC, is concerned with allocating the actual cost of doing business to some cost object, usually a product or service. In a manufacturing environment, the cost per unit, c, is obtained from the cost accounting system. The system provides this cost by first accumulating the direct labor and materials cost for each product produced in the period and then allocating to each product a portion of the manufacturing overhead. Finally, the total cost allocated to each product is divided by the number of products produced to obtain c. If we do not manufacture the products, but rather purchase the inventory from the manufacturer, the accounting system will accumulate not only the purchase price per unit, but also the costs associated with obtaining and holding the product. Because the actual costs vary from period to period, manufacturing firms often establish "standard" costs based on past history and use these standard costs to value inventory. For example, a standard or average labor rate may be used instead of the actual labor rate or a standard overhead charge per unit is applied rather than the actual overhead for the period. Thus the value of c used in the EOQ model, defined as a per-unit cost, will most likely be a standard cost, which is updated periodically.

Exactly what is included in c will depend on the overhead allocation method, so we must be careful when obtaining the value of c from the cost accounting system. For instance, if the manufacturing overhead allocated to the different products includes warehouse rental, inventory taxes or insurance, then h is included in the cost per unit and we must delete these items to obtain c. Similarly, the price per unit may include components of a, such as freight charges or setup supplies. Finally, the value of a and h will depend on how the cost system allocates costs to the departments or activities responsible for placing and receiving orders, performing setups and handling inventory.

Obviously, it is very important that the industrial engineer performing an EOQ analysis understand the accounting system that is used to derive the cost parameters in the model.

One way to derive *a* and *h* is to look at the cost drivers assigned to each activity in the ABC system. Those activities that can be allocated based on number of setups and those that vary with the average number of units in inventory can be selected to represent *a* and *h* respectively. But not all activities related to setups, orders or inventory can be allocated in this manner. For example, the salary of personnel dedicated to performing setups will be the same (within a range) regardless of the number of setups performed. Similarly, the warehouse rental does not necessarily vary with the average number of units in stock. Thus some costs will be excluded from the EOQ analysis if we use this method for calculating *a* and *h* and those costs may be important in the long-term. We can also develop approximate values for *a* and *h* by allocating all the relevant costs based on number of setups or average inventory in stock, assuming that these are the most important cost drivers. Alternatively, it may be necessary to revise the EOQ model to accommodate other cost drivers. An ABC analysis and the resulting cost allocation may influence how we build this model.

Single Product

For the single-item model, ABC has no effect on the model parameters, as long as we use number of setups and average inventory as the drivers. Manufacturing costs (both direct and indirect) are allocated to one product regardless of how many activities may be involved. Suppose there are two activities for inventory and ordering costs: warehousing and purchasing. Since only one item will consume the warehouse and purchasing activities, the total inventory costs and order costs are allocated to one product. Thus *h* and *a* are unaffected by ABC. The single item EOQ model may still need to be revised if number of setups and average inventory are not the most relevant cost drivers, as we will see later.

Setup Costs

Number of Clerks as the Cost Driver

As noted earlier, we assume in the EOQ model that a represents the fixed cost of placing each order and that it is constant regardless of the number of orders placed in a given time period. In reality this is often not true and the ABC system will reveal this through the analysis of cost drivers. For example, consider the case where the activity of placing an order is done by a purchasing clerk and the most significant cost driver in the purchasing department is the number of clerks. In this case, the total cost would vary not with the number of orders placed, but with the number of clerks employed. Of course, we recognize that each clerk has a maximum number of orders that he/she can process in a given period of time (capacity), so the ABC system would allocate the cost of the purchasing department to the products based on the usage of this capacity.

Note that this is a long term approach to the problem, as opposed to the short-term view traditionally taken by the EOQ model. In the short term, the number of clerks is fixed, so that if there are n clerks and each clerk costs k per period, the total cost is nk and this term will not affect the order quantity. However, as we will see later, in the long term, we seek to find not only the optimal order size, but also the optimal number of clerks, since this is the significant cost driver in the purchasing department. While conventional economics treats costs as variable only if they change with short term fluctuations in output, numerous ABC case studies show that many important cost categories do not vary with short term changes, but with changes over a period of years (Bakke and Hellberg, 1991). A key assumption underlying activity-based analysis is that almost all indirect and support costs are variable. Many indirect expenses (such as the salaries paid to the purchasing clerks) will not vary from month to month with changes in the volume and mix of monthly production, so they appear to be fixed in the short run. They become variable, however, each year during the budgeting cycle when the organization authorizes annual spending levels for each of its support departments. If the production environment has become more complex because of a greater number of transactions (setups or orders) then eventually more support people and resources have to be added to the organization (Kaplan, 1989).

Suppose that a clerk can process m orders per time period and is paid a salary k during that time period. Then it is reasonable to estimate that $a = k/m$ and this will in fact be true if the actual number of orders is m. If, however, the number of orders placed during the time period is less than m, the total cost of the ordering activity will still be k, not $a\frac{D}{Q}$ as the EOQ model assumes. In this case, the EOQ model will underestimate the total cost $f(Q)$ by the amount of excess capacity: $a(m-\frac{D}{Q})$. The actual total cost for the period is

$$f(Q) = k\left\lceil \frac{D}{Qm} \right\rceil + h\frac{Q}{2} + cD$$

where $\left\lceil \frac{D}{Qm} \right\rceil$ is the nearest integer greater than or equal to $\frac{D}{Qm}$. We note that the maximum error in the total cost will be k and that the true value of a is $\frac{k}{D/Q}$. Suppose we can afford only one clerk. Then the problem can be formulated as

$$\begin{aligned} &\min\ f(Q) = k + h\frac{Q}{2} + cD \\ &\text{s.t.}\ \frac{D}{Q} \le m \end{aligned}$$

The solution, $Q^* = \frac{D}{m}$ is trivial, since we will seek to minimize Q in order to reduce our inventory costs, given that the total cost of ordering is constant. Of course this results in using our order resource to maximum capacity. A similar analysis can be made for any number of clerks, say nk. In this case we set $Q^* = \frac{D}{mn}$ in order to minimize the inventory cost. Comparing this to the traditional model, we note that the constraint in the above equation requires that $EOQ \geq \frac{D}{mn}$, thus the traditional model will always result in the total cost being greater than or equal to the total cost with Q^*. The observation that the order cost is fixed for a certain capacity is highlighted by the ABC system, with its emphasis on the long-term cost of activities.

Multiple Products

If we allow multiple products, then we have several products consuming the warehousing and purchasing activities. ABC allows us to recognize the fact that not all products consume activities at the same rate. By identifying the appropriate activity drivers, each product i will have cost per unit c_i, inventory cost per unit h_i and setup cost a_i. Thus we will have for each item

$$EOQ_i = \sqrt{\frac{2a_iD_i}{h_i}}$$

Because ABC will likely result in different inventory and setup rates for each product, a multi-product EOQ model is necessary. Such a model is often bound by a set of constraints, such as space, budget, or number of orders per time period. In this case the unconstrained optimal lot size for each product may not satisfy the constraints and the problem may be solved using the Kurush-Kuhn-Tucker (KKT) conditions.

Let us go back to the case where the number of clerks is the cost driver for the purchasing department. Suppose the clerk can process m_i orders of product *i* in each time period (for example, a clerk could process 500 orders for product 1 or 250 orders for product 2 in one year). Thus the capacity of the clerk is given by

$$\sum_i \frac{D_i}{Q_i m_i} \le 1$$

We can formulate this problem as

$$\begin{aligned} &\min\ f(Q) = k + \sum_i h_i \frac{Q_i}{2} + \sum_i c_i D_i \\ &\text{s.t.}\ \sum_i \frac{D_i}{Q_i m_i} \le 1 \end{aligned}$$

In general we have the following problem

$$\begin{aligned} &\min f(Q) = k\left\lceil \sum_i \frac{D_i}{Q_i m_i} \right\rceil + \sum_i h_i \frac{Q_i}{2} + \sum_i c_i D_i \\ &\text{s.t.}\ \sum_i \frac{D_i}{Q_i m_i} \le N \end{aligned}$$

where *N* is an integer representing the maximum number of clerks and we require at least one clerk (otherwise the orders cannot be placed). Let us relax the integer requirement in the objective function and solve the problem without the capacity constraint. In this case we have

$$g(Q) = k\sum_i \frac{D_i}{Q_i m_i} + \sum_i h_i \frac{Q_i}{2} + \sum_i c_i D_i$$

which is a strictly convex function with a unique global minimum at

$$EOQ_i = \sqrt{\frac{2D_i k}{h_i m_i}}$$

Proof:

Since $g(Q_i)$ is a function of a single variable, Q_i, we need only show that the second derivative of $g(Q_i)$ is strictly positive for all values of Q_i to show that it is strictly convex.

$$g'(Q_i) = -\frac{kD_i}{Q_i^2 m_i} + \frac{h_i}{2}$$
$$g''(Q_i) = \frac{2kD_i}{Q_i^3 m_i}$$

Since Q_i, a_i, D_i, k, $m_i > 0$ (model constraints), then $g''(Q_i) > 0$ for all values of $Q_i > 0$ and $g(Q_i)$ is strictly convex. Thus $g(Q)$ is the sum of strictly convex functions and is therefore also a strictly convex function with a unique global optimum at $\nabla g(Q^*) = 0$. *QED.*

We can also make the following observations (refer to Figure 3-1):

1. $g(Q)$ is a lower bound on $f(Q)$, since by definition $\left\lceil \sum_i \frac{D_i}{Q_i m_i} \right\rceil \geq \sum_i \frac{D_i}{Q_i m_i}$.

2. $f(Q) = g(Q)$ at every integer value of $\sum_i \frac{D_i}{Q_i m_i}$.

3. $f(Q) > g(Q)$ between any two adjacent integer values of $\sum_i \frac{D_i}{Q_i m_i}$.

4. $f(Q)$ is linear between any two integer values of $\sum_i \frac{D_i}{Q_i m_i}$.

5. Since $g(Q)$ has a unique global minimum at EOQ_i, we know that if $\sum_i \frac{D_i}{EOQ_i m_i} = n$, then $f(Q)$ will also be minimized at $Q_i^* = EOQ_i$.

6. Since $g(Q)$ is a strictly convex function with a global minimum, its value will increase as we move away from EOQ_i in *any* direction.

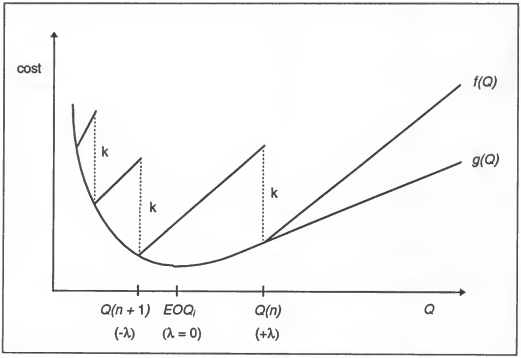

Figure 3-1. Cost vs. Order Quantity

Although the EOQ_i solution is optimal for $g(Q)$, it may not be feasible when we consider the first constraint, $\sum_i \frac{D_i}{Q_i m_i} \le N$. Since $g(Q)$ is strictly convex and there is only one constraint, we can use the KKT conditions to obtain the optimal solution. Solving for Q we obtain:

$$Q_i = \sqrt{\frac{2D_i(k+\lambda)}{h_i m_i}}$$

were the λ is the KKT multiplier given by

$$\lambda = \frac{\left(\Sigma\sqrt{\frac{D_i h_i}{2m_i}}\right)^2}{N^2} - k$$

substituting this for λ into Q_i above, we obtain the optimal solution:

$$Q_i{*} = \frac{1}{N}\sqrt{\frac{2D_i}{h_i m_i}} \cdot \sum_j \sqrt{\frac{D_j h_j}{2m_j}}$$

This solution results in using *N* clerks to maximum capacity, thus reducing the average inventory size as much as possible.

Since the two terms under radical signs in $Q_i*(N)$ are constant for each *i* we can write

$$Q_i*(N) = \frac{\gamma_i}{N}$$

where $\gamma_i = \sqrt{\frac{2D_i}{h_i m_i}} \cdot \sum_j \sqrt{\frac{D_j h_j}{2m_j}}$.

Now suppose we find EOQ_i but $\sum_i \frac{D_i}{EOQ_i m_i} = x$, where *x* is *not* an integer. Then we know from (3) that we can improve the value of *f(Q)* by simply moving to an integer on either side of *x*. Let $\lfloor x \rfloor = n$ and $\lceil x \rceil = n+1$. If $\sum_i \frac{D_i}{Q_i^* m_i} = n$, then $Q_i^*(n) > EOQ_i$ because $n < x$ and if $\sum_i \frac{D_i}{Q_i^* m_i} = n+1$, then $Q_i^*(n+1) < EOQ_i$ because $n+1 > x$.

Furthermore, for any integer $q < n < x$, $Q_i^*(q) > Q_i^*(n) > EOQ_i$. Since *g(Q)* is strictly increasing from EOQ_i to infinity, $g(q) > g(n) > g(EOQ_i)$ and from (2) $f(q) > f(n) > f(EOQ_i)$. Likewise, for any integer $p > n + 1 > x$, $Q_i^*(p) < Q_i^*(n+1) < EOQ_i$. Since $g(Q)$ is strictly decreasing from zero to EOQ_i, $g(p) > g(n+1) > g(EOQ_i)$ and from (2) $f(p) > f(n+1) > f(EOQ_i)$. Thus we can conclude the unconstrained optimal solution for $f(Q)$ will be found at either n or $n+1$ (or possibly both).

In order to determine which is better, n *or* $n + 1$, we need to compare the value of $f(Q)$ at these two points. Letting $Q_i^*(n) = \frac{\gamma_i}{n}$ we have

$$f(n) = nk + \sum_i \frac{h_i\gamma_i}{2n} \text{ and } f(n+1) = (n+1)k + \sum_i \frac{h_i\gamma_i}{2(n+1)}$$

$$f(n+1) - f(n) = k - \frac{1}{n(n+1)} \sum_i \frac{h_i\gamma_i}{2}$$

therefore $f(n) \leq f(n+1)$ if $k \geq \frac{1}{2n(n+1)} \sum_i h_i\gamma_i$. We note that when the above terms are equal, $f(Q)$ will have two optima, at $Q^*(n)$ and $Q^*(n+1)$.

To solve the original problem, we first need to find the optimal number of clerks, N^*. This is because even if $\sum_i \frac{D_i}{EOQ_i m_i} < N$ and we have met the capacity constraint, $\sum_i \frac{D_i}{EOQ_i m_i}$ may not be an integer and therefore EOQ_i will not yield an optimal solution, as shown above. In this case the capacity constraint becomes either $\sum_i \frac{D_i}{EOQ_i m_i} = n$ or $\sum_i \frac{D_i}{EOQ_i m_i} = n + 1$. Note that when $Q_i^* = EOQ_i$ we have $\lambda = 0$ as shown in Figure 3-1. When we solve for $Q_i^*(n)$ λ will be positive (since we have reduced the capacity from x to n) and when we solve for $Q_i^*(n+1)$ it will be negative (since we have increased the capacity from x to $n + 1$). Thus λ is no longer the traditional KKT multiplier, but is simply being used to adjust the value of Q_i^* to obtain an integer value for $\sum_i \frac{D_i}{Q_i^* m_i}$.

To obtain the optimal order quantity, we first look at the number of clerks required to process the EOQ_i amounts, $\sum_i \frac{D_i}{EOQ_i m_i}$, then compare this amount to N and solve for Q_i*. We have three cases:

Case 1: $\sum_i \frac{D_i}{EOQ_i m_i} < N$ and *not* an integer.

Let $\sum_i \frac{D_i}{EOQ_i m_i} = x$, $\gamma_i = \sqrt{\frac{2D_i}{h_i m_i}} \cdot \sum_i \sqrt{\frac{D_i h_i}{2m_i}}$, $\lfloor x \rfloor = n$ and $\lceil x \rceil = n+1$

If $k \geq \frac{1}{2n(n+1)} \sum_i h_i \gamma_i$, then $N^* = n$, otherwise, $N^* = n+1$

and $Q_i{}^* = \frac{1}{N^*} \sqrt{\frac{2D_i}{h_i m_i}} \cdot \sum_j \sqrt{\frac{D_j h_j}{2m_j}}$

Case 2: $\sum_i \frac{D_i}{EOQ_i m_i} \leq N$ and an integer *n*.

Then $N^* = n$ and $Q_i{}^* = EOQ_i$

Case 3: $\sum_i \frac{D_i}{EOQ_i m_i} > N$.

then $N^* = N$ and $Q_i{}^*(x) = \frac{1}{N} \sqrt{\frac{2D_i}{h_i m_i}} \cdot \sum_j \sqrt{\frac{D_j h_j}{2m_j}}$

Note that the third case implies that an increase in the number of clerks could lead to a better solution. To find that solution, we would treat case 3 in a manner similar to case 1: let $\lfloor x \rfloor = n$ and $\lceil x \rceil = n+1$, where $\sum_i \frac{D_i}{EOQ_i m_i} = x$, then compare $Q^*(n)$ to $Q^*(n+1)$ to find the optimal solution and the optimal number of clerks, N^*. Again, this would involve both a positive λ (for *n*) and a negative λ (for $n + 1$).

Fixed and Variable Setup Costs

In reality, there are both fixed and variable components in the total setup costs:

$$A = k + ax$$

where x is some cost driver (for example, $\frac{D}{Q}$), a is the cost per unit of driver x and k is the component that does not vary with x and is therefore a "fixed" cost. Traditionally, the EOQ model has chosen to use the number of setups as the cost driver so that $x = \frac{D}{Q}$ and $k = 0$ in the equation above. This may be appropriate if the number of setups is indeed the primary cost driver for the setup activity. An ABC analysis of the manufacturing process would confirm this, or it may reveal that other costs (k) are also significant and should not be allocated based on number of setups, or that another cost driver may be more appropriate. The point is that we must choose x carefully, so that k is small relative to ax in order to minimize the distortion, or we may decide to use more than one cost driver. For example, we can revise the traditional EOQ model to recognize that a portion of the total setup cost varies with the number of purchasing personnel, while a portion is constant from order to order. Again we assume one person costs a fixed amount k and can process a maximum of m_i orders of product i in each time period:

$$\begin{aligned} \min f(Q) &= k\left\lceil \sum_i \frac{D_i}{Q_i m_i} \right\rceil + \sum_i \left[a_i \frac{D_i}{Q_i} + h_i \frac{Q_i}{2} + c_i D_i \right] \\ \text{s.t. } &\sum_i \frac{D_i}{Q_i m_i} \le N \end{aligned}$$

We can relax the integer requirement and solve without the first constraint:

$$\min g(Q) = k \sum_i \frac{D_i}{Q_i m_i} + \sum_i \left[a_i \frac{D_i}{Q_i} + h_i \frac{Q_i}{2} + c_i D_i \right]$$

Since $g(Q)$ is a strictly convex function, it has a global optimum at $\nabla g(Q^*) = 0$.

Proof:

Since $g(Q_i)$ is a function of a single variable, Q_i, we need only show that the second derivative of $g(Q_i)$ is strictly positive for all values of Q_i to show that it is strictly convex.

$$g'(Q_i) = -\frac{kD_i}{Q_i^2 m_i} - \frac{a_i D_i}{Q_i^2} + \frac{h_i}{2}$$
$$g''(Q_i) = \frac{2kD_i}{Q_i^3 m_i} + \frac{2a_i D_i}{Q_i^3}$$

Since Q_i, a_i, D_i, k, $m_i > 0$ (model constraints), then $g''(Q_i) > 0$ for all values of $Q_i > 0$ and $g(Q_i)$ is strictly convex. Thus $g(Q)$ is the sum of strictly convex functions and is therefore also a strictly convex function with a unique global optimum at $\nabla g(Q^*) = 0$. *QED.*

Solving for Q_i^*, we obtain EOQ_i

$$EOQ_i = \sqrt{\frac{2D_i}{h_i m_i}(k + a_i m_i)}$$

We can now check to see if this solution satisfies the first constraint, $\sum_i \frac{D_i}{Q_i m_i} \leq N$. If it does not, then the constraint is binding and we use the KKT conditions to obtain the following equations:

$$Q_i = \sqrt{\frac{2D_i}{h_i m_i}(k + a_i m_i + \lambda)} \qquad (1)$$

and
$$\sum_i \left[\frac{D_i / m_i}{\sqrt{\frac{2D_i}{h_i m_i}(k + a_i m_i + \lambda)}} \right] = N \qquad (2)$$

Unfortunately, we cannot solve for λ directly, since $a_i m_i$ is not constant for all *i*.

Let $\gamma = \frac{\sum_i \frac{D_i}{EOQ_i m_i}}{N}$ and $\overline{Q}_i = \gamma \cdot EOQ_i$, then $\sum_i \frac{D_i}{\overline{Q}_i m_i} = \frac{1}{\gamma} \sum_i \frac{D_i}{EOQ_i m_i} = N$.

This satisfies equation (2), but with a different λ_i for each $\overline{Q}_i$ which we obtain by setting $\overline{Q}_i = Q_i *$ in equation (1):

$$\lambda_i = (k + a_i m_i)(\gamma^2 - 1)$$

Because equation (2) is a strictly decreasing function of λ, it can be shown that $\min\{\lambda_i\} < \lambda^* < \max\{\lambda_i\}$ (Ventura and Klein, 1988) and we can find λ^* using a bi-section search.

Note that we can make the same observations on *f(Q)* and *g(Q)* as we did earlier:

1. *g(Q)* is a lower bound on *f(Q)*.
2. *f(Q)* =*g(Q)* at every integer value of $\sum_i \frac{D_i}{Q_i m_i}$.
3. *f(Q)* > *g(Q)* between any two adjacent integer values of $\sum_i \frac{D_i}{Q_i m_i}$.
4. *f(Q)* is linear between any two integer values of $\sum_i \frac{D_i}{Q_i m_i}$.
5. Since *g(Q)* has a unique global minimum at EOQ_i, we know that if $\sum_i \frac{D_i}{EOQ_i m_i} = n$, then *f(Q)* will also be minimized at $Q_i^* = EOQ_i$.

6. Since $g(Q)$ is a strictly convex function with a global minimum at EOQ_i, its value will increase as we move away from EOQ_i in *any* direction.

We can also show, as we did earlier, that the optimal solution for $f(Q)$ will be found at either n or $n+1$ (or possibly both). Returning to our original problem $f(Q)$, the optimal solution will be based on the optimal number of clerks (an integer, as shown above). There are three possible cases:

Case 1: $\sum_i \frac{D_i}{EOQ_i m_i} < N$ and *not* an integer.

Set $\lfloor x \rfloor = n$ and $\lceil x \rceil = n+1$ where $\sum_i \frac{D_i}{EOQ_i m_i} = x$

Find $\lambda^*(n)$ and $\lambda^*(n+1)$

Compute $Q_i^*(n)$ and $Q_i^*(n+1)$ where $Q_i^*(n) = \sqrt{\frac{2D_i}{h_i m_i}[k + a_i m_i + \lambda^*(n)]}$

Compare $f[Q_i^*(n)]$ to $f[Q_i^*(n+1)]$ and select the lower cost. Note that N^* will be either n or $n+1$ (or possibly both) based on this comparison.

Case 2: $\sum_i \frac{D_i}{EOQ_i m_i} \leq N$ and an integer n.

then $N^* = n$ and $Q_i^* = EOQ_i$

Case 3: $\sum_i \frac{D_i}{EOQ_i m_i} > N$.

Set $\sum_i \frac{D_i}{EOQ_i m_i} = N$ and solve for λ^*. Note that $N^* = N$.

$$Q_i^* = \sqrt{\frac{2D_i}{h_i m_i}(k + a_i m_i + \lambda^*)}$$

Since the optimal solution is an integer value of $\sum_i \frac{D_i}{EOQ_i m_i}$, the first case involves finding the optimal number of clerks as well as the optimal order quantity, because we are adjusting the capacity constraint from x to either n or $n + 1$. Also, case 3 could be used to justify an increase in the number of clerks, as shown in the previous section.

Inventory Costs

In the simple EOQ model the total inventory cost is a function of volume, Q. This assumes that the cost driver is average inventory in stock $(\frac{Q}{2})$. In reality, inventory cost may be more dependent on other drivers, such as the size of the product or the amount of handling required, or even the total number of items handled D. If the allocation of the warehouse cost is made at the product level then it will not vary with the average number of units in stock.

For example, suppose warehouse costs are to be allocated to two products: X is a small, easy to handle product, while Y is a large, cumbersome product requiring special machinery. If costs are allocated based on size, we might allocate 25% of the warehouse costs to product X and 75% of the costs to product Y. The 75% is then allocated to the individual units of Y based on average volume in stock $(\frac{Q_Y}{2})$ to determine h_Y. Thus we see that the higher the lot size, the smaller h_Y will be. This is because regardless of volume, product Y must absorb 75% of the costs. Of course, this is an oversimplification. In reality we would probably have two cost drivers for warehousing, one for fixed costs (such as machinery) and another for variable costs (such as insurance), so that the total warehouse cost is

$$H = k + hy$$

where hy is the portion that varies with the average level of stock and k is the portion that is fixed. If h is the dominant term, then we may use $H = h$ as is the case in the traditional EOQ model. If, however, k is the dominant term, then H no longer varies with the average number of units in stock, as shown above. To incorporate both terms we must revise the EOQ cost function as follows:

$$f_{x,y}(Q) = \frac{aD}{Q} + g(x) + \frac{hQ}{2} + h(y) + cD$$

where $g(x)$ represents the portion of the setup activity that is fixed or may vary with a cost driver other than number of setups and $h(y)$ is the portion of the warehousing activity that is fixed or varies with a cost driver other than average volume.

Number of Warehouses as Cost Driver

Suppose, for example, that the warehouse rental is k for a given size of warehouse. Each warehouse can accommodate up to m_i units of product i. We now have a situation similar to the step function for setup costs. If the stock level exceeds the capacity of the warehouse, the company must rent another warehouse. Thus we have the following model

$$\min f(Q) = k\left\lceil \sum_i \frac{Q_i}{m_i} \right\rceil + \sum_i \left[a_i \frac{D_i}{Q_i} + h_i \frac{Q_i}{2} + c_i D_i \right]$$

$$\text{s.t. } \sum_i \frac{Q_i}{m_i} \leq N$$

where N is the maximum number of warehouses available.

A procedure similar to the one used for the order step function can be used to solve for this model. We first solve the problem without the integer requirement and the warehouse constraint:

$$\min\ g(Q) = k\sum_i \frac{Q_i}{m_i} + \sum_i \left[a_i \frac{D_i}{Q_i} + h_i \frac{Q_i}{2} + c_i D_i \right]$$

it can be shown that this is a strictly convex function with a global minimum at $\nabla g(Q^*) = 0$ and that minimum is

$$EOQ_i = \sqrt{\frac{2a_i D_i m_i}{2k + h_i m_i}}$$

When we include the warehouse constraint, $\sum_i \frac{Q_i}{m_i} \le N$, we first check to see if the *EOQ$_i$* quantities satisfy the constraint. If not, we use the KKT conditions to obtain

$$Q_i = \sqrt{\frac{2a_i D_i m_i}{2(k + \lambda) + h_i m_i}}$$

Again, we cannot solve for λ^* directly, since $h_i m_i$ is not constant from product to product, but we can use a bi-section search between $\min\{\lambda_i^*\}$ and $\max\{\lambda_i^*\}$ to find the optimum λ, where

$$\lambda_i = \frac{2k + h_i m_i}{N^2}\left[\sum_i \frac{EOQ_i}{m_i}\right]^2 - k - \frac{h_i m_i}{2}$$

We have three possible cases:

Case 1: $\sum_i \frac{EOQ_i}{m_i} < N$ and *not* an integer

Set $\lfloor x \rfloor = n$ and $\lceil x \rceil = n+1$ where $\sum_i \frac{EOQ_i}{m_i} = x$

Find $\lambda^*(n)$ and $\lambda^*(n+1)$

Compute $Q_i^*(n)$ and $Q_i^*(n+1)$ where $Q_i^*(n) = \sqrt{\frac{2a_i D_i m_i}{2(k + \lambda^*) + h_i m_i}}$

Compare $f[Q_i^*(n)]$ to $f[Q_i^*(n+1)]$ and select the lower cost. Note that N^* will be either n or $n+1$ (or possibly both) based on this comparison.

Case 2: $\sum_i \frac{EOQ_i}{m_i} \leq N$ and an integer n

then $N^* = n$ and $Q_i^* = EOQ_i$

Case 3: $\sum_i \frac{EOQ_i}{m_i} > N$

Set $\sum_i \frac{EOQ_i}{m_i} = N$ and solve for λ^*. Note that $N^* = N$.

$$Q_i^* = \sqrt{\frac{2a_i D_i m_i}{2(k+\lambda^*)+h_i m_i}}$$

Conclusion

We see that ABC seeks to reveal a more accurate picture of the product cost and allocates fixed as well as variable manufacturing overhead to the products. If, for the sake of simplicity we choose to ignore the fixed costs and base our EOQ analysis on variable costs (which vary with Q), then our results may be distorted. In this chapter we examined cases where other cost drivers, such as the number of clerks or the number of warehouses are significant cost drivers. By relating these drivers to the order quantity (as a step function of Q), we were able to show how they can impact the optimal order quantity. Of course, if there is no relation between a cost driver and Q (this would be the case if the cost in question is fixed for all levels of Q), then the optimal order quantity would not be impacted by that cost driver. The total cost, however, would still be impacted and minimizing total cost would involve finding not only the optimal Q, but also optimizing other cost drivers.

The key point here is that the ABC analysis will not only change the values of *c, a* and *h* in the EOQ model (which might change the value of the optimal lot size, Q^*), but it might also affect the validity of the assumptions in that model. If this is the case, the ABC cost allocation will provide incentive to the manufacturing department to change the EOQ model. The incentive will come from the allocation of costs which the manufacturing department is trying to control. In order to control costs, the industrial engineers in the manufacturing department will have to make the same assumptions (about cost drivers and cost behavior) that the ABC model is making. Otherwise, they will be frustrated in their efforts and will erroneously assume that the cost system is irrelevant.

CHAPTER 4
INVESTMENT ANALYSIS

Activity-based Investment

Management must be able to go beyond cost when choosing between investment alternatives. To remain competitive, firms must incorporate strategic goals into their investment decisions and these goals often involve non-financial benefits, such as quality, efficiency, flexibility and customer satisfaction, to name a few. The inadequacy of traditional investment analysis in evaluating non-financial benefits is well known and has resulted in the use of multi-attribute decision techniques, like AHP, to account for such factors (Canada and Sullivan, 1989). These techniques, while taking into account the non-financial benefits, fail to consider the impact of investment alternatives on activities. Rather, they simply consider cost (usually net cost savings) as one of the decision attributes within the model. By ignoring the impact on activities, the models fail to prioritize investments based on how they will affect the business process. The result is that the model often favors an investment that has significant benefits to a single department or activity, without considering the relative importance of that activity to the overall business process and the strategic goals (Brimson, 1989).

The natural extension to ABC and ABM is activity-based investment management. Brimson (1989) provides a framework for this based on an analysis of the activities that influence cost and quality in a modern manufacturing environment. Traditional investment analysis (using discounted cash flow techniques) is based on the cash flow impact of each investment alternative, a process that does not take into account important non-monetary decision parameters such as quality and efficiency. Scoring techniques, such as the multiattribute decision model, integrate non-monetary factors into the decision process, but do not account for the impact of the cash flow on the business process.

In addition, the traditional view compares investment alternatives proposed by individual department managers based on the benefits to each department without analyzing the effect of the investment on the activities and goals of the company. This can result in short-term solutions that treat the symptoms of a problem. Getting to the root cause of the problem requires an understanding of the cost drivers. An effective investment management system identifies those cost drivers with the greatest impact on activities and those activities with the greatest impact on the success of the organization. By allocating the investment cash flow to the activities, management can understand the effect of the investment on cost drivers and activities.

While traditional investment strategies seek to control costs, activity-based investment seeks to control the costs of the activities themselves. This approach can help lower costs by identifying cost drivers and allocating scarce resources to critical activities. Brimson suggests that before comparing investment alternatives a company needs to identify the activities that support company goals. Activities provide a consistent basis for analyzing investments and monitoring the actual results through an ABC accounting system. The investment analysis is then based on improving the performance of value-added activities and the elimination or minimization of non-value-added activities. The impact of an investment on the cost of these activities is determined through ABC analysis, which computes the estimated cost of each activity under a given investment alternative. Alternatives are also evaluated based on their impact on performance measures associated with each activity and a portfolio of investments is established for each key performance measure. The investments that both improve performance and meet or exceed a target ROI are the most desirable.

Non-financial Considerations

Sawhney (1991) has developed a methodology for evaluating manufacturing investments that are heavily influenced by non-financial considerations. Like Brimson, Sawhney suggests that investments should be evaluated in terms of the strategic objectives of the firm (in addition to the traditional financial analysis) and on their impact on production-related activities. The objective of the approach is to select investments that provide the greatest improvement to key activities as measured by critical success factors. Sawhney assumes that key manufacturing activities have been identified by management prior to the analysis (this is in fact true if an ABC system has been implemented by the firm).

Sawhney uses simulation models to evaluate the performance of various activities within the manufacturing system under different investment alternatives. The results of the simulation are performance measures such as lead time, operational output, average inventory level and equipment utilization. In addition, management provides a subjective evaluation of the importance of each activity relative to the performance measures used to analyze the investments. The effects of each investment on specific manufacturing goals are then evaluated based on target levels. The investments are ranked using subjective weights for the contribution of each manufacturing goal to the overall strategy. Finally, a normalized importance weight is assigned to the results of the performance analysis as well as to other critical attributes (such as net present value, riskiness and price) and the investment selection is made based on the highest overall score.

We propose to formalize the definition of the relationships between manufacturing goals, activities and the investment decision by using AHP. This method provides a more consistent weighting scheme than other scoring techniques (see Chan and Lynn, 1993) for a comparison of discounted cash flow analysis, the multiple-attribute decision model and

AHP). We will then use ABC to develop the cost relationships among investment alternatives and activities and AHP to define the link between investment alternatives, performance measures and activities. Once these relationships have been established we will incorporate them into two separate decision models: a cost impact model and a performance impact model.

The advantage of AHP is that it provides a framework for prioritizing goals, objectives and alternatives. In our decision model, discussed in the next section, AHP ensures that strategic goals (or manufacturing goals based on strategic goals) are used as a basis for making investment decisions. It is used to determine how performance measures are related to goals and how activities contribute to performance measures.

Decision Model

Investments affect activities in two ways: by altering the way they are performed (in some cases eliminating them) and by changing the cost of the resources consumed by the activity. The first effect can be seen through changes in performance measures. The second effect can be seen through changes in the cost of the activities. The two changes are combined to produce a new cost allocation rate for each activity, which in turn will affect the cost and profitability of products and services using the activities (see Figure 4-1). We propose to evaluate the performance and cost impact using two separate models: a cost impact model and a performance impact model.

The methodology consists of the following steps:

> *Step 1:* Define the relationship between activities and strategic goals by using AHP techniques to rank activities in terms of strategic goals. This step will also define the relative importance of the strategic goals.
>
> *Step 2:* For each investment alternative, determine the net dollar effect on resources, including capital investment. Distribute this net effect from resources to activities using ABC techniques.

Step 3: Define the relationship between activities and performance measures by using AHP techniques to rank activities in terms of performance measures.

Step 4: Combine steps 1 and 2 into a cost impact model to determine the cost score for each investment alternative.

Step 5: Combine steps 1 and 3 into a performance impact model to determine the performance score for each investment alternative.

Step 6: Plot the cost and performance scores of each alternative on a cost vs. performance graph to select the best investment alternative(s).

We will discuss the cost impact model first and illustrate it with an example. Then we will discuss and illustrate the performance impact model. Finally we will illustrate the use of the cost vs. performance graph to select the best investment alternative in our example.

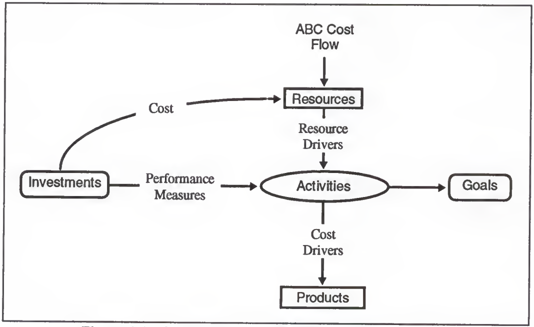

Figure 4-1. Cost and Performance Impact of Investments

Cost Impact

By analyzing the resources consumed as a company performs its activities and measures its performance, management can identify areas where change may achieve significant cost reductions. We can accomplish this by allocating the cost impact of investments to critical activities using ABC drivers, in essence performing a "what-if" analysis of the investment. This provides an objective assessment of the cost effect of each investment, not only in terms of net present value but also in terms of the business process. Failure to allocate the cost impact of investments to critical activities would limit management's ability to control and improve the performance of these activities through capital investment. In addition, the evaluation of investments in terms of activities allows the analyst to account for various operational interdependencies that are not captured by traditional stand-alone analysis of capital investments. Detecting the impact of an investment on activities allows for a more realistic evaluation of alternatives which improves the selection process (Sawhney, 1991).

When the cost savings are determined for each investment, the effect on cost drivers (e.g., quality, cycle time, productivity) must be considered. This involves a thorough examination of how the investment will change the performance of each activity and therefore the consumption of resources. Although the cost drivers are not considered individually, the overall impact of each investment on the cost drivers is imbedded in this analysis. For instance, we may note that a particular machine reduces raw material waste. This savings results from changes to cost drivers such as quality and productivity. Rather than trying to determine how much of this savings is attributable to each cost driver, we consider the aggregate effect on resource consumption.

The cost allocation does not, however, provide information on the relative merit of the cost effects. Our methodology provides this crucial step by linking the activities to the strategic goals using AHP. Without this step, management must intuitively determine if, for example, cost savings in one activity are more important than cost savings in another activity. As Brimson notes, a common complaint among manufacturing executives is that traditional investment analysis methods often fail to justify advanced manufacturing technologies, even though managers believe the company should make the investment to remain competitive. Our cost impact model seeks to quantify this intuition and provide managers with an alternative assessment of the cost impact of investments.

Let us assume that manufacturing costs are allocated using ABC. Specifically, actual expenses for labor, materials and overhead are accumulated in resource cost pools and allocated to activities using resource drivers. This is the first stage of ABC. Each investment will have a measurable effect on the cost of resources and thus on the total labor, materials and overhead accumulated in the cost pools. Using traditional forecasting methods, we can estimate the periodic operating costs, as well as the resource driver usage, of each investment alternative. Both these estimates are then incorporated into the ABC model to allocate the cost effects of the investment to the activities. We will allocate the net cost savings (or cost increase) in each resource pool to the activities, using the estimated driver quantities. This procedure is done separately for each investment alternative.

In addition to the operating costs, we also compute the periodic annuity that is equivalent to the initial cost of the investment (purchase price plus installation and startup costs less salvage). We add this to the ABC model as a resource pool and allocate it to the activities based on machine hours. This allows us to include the initial capital outlay in our cost analysis (see Figure 4-2). Note that in order to compare investment alternatives with different lives, we can either discount both alternatives using a limited planning horizon (coterminated assumption) or we can use the lowest common multiple of the lives of the alternatives (repeatability assumption). Alternatively, if cash flows from the shorter-lived project can be assumed to be reinvested at a relevant rate, we can incorporate this into our calculations (see Clark, Hindelang and Pritchard, 1979 for a discussion of projects with unequal useful lives).

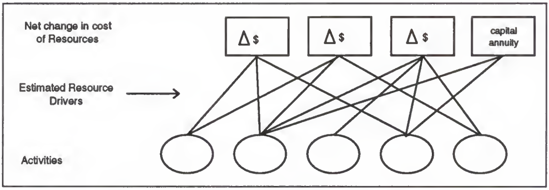

Figure 4-2. Allocation of Cost Impact to Activities

Once we have allocated the cost impact of each investment to the activities, we have a net change in cost for each activity under each investment scenario. We can use these dollar figures to connect the activities to our investment alternatives in our cost impact model. The rest of the model (above the activities) is based on AHP, as shown in Figure 4-4.

Our cost impact model is basically an AHP model modified at one level to incorporate ABC. Our overall objective is to choose among several investment alternatives. In AHP terms, the strategic goals are attributes and the activities are sub-attributes. The priority weights for the strategic goals and activities are determined using pairwise comparisons. The priority weights linking the investment alternatives to the activities are derived from the allocation of resource dollars in the first stage of the ABC model. Once all the priority weights have been determined, we multiply the weights along each path leading to an alternative and add them to arrive at a score for that alternative.

Assigning priority weights to the investment alternatives based on the ABC model (instead of pairwise comparison) results in several important differences between our cost impact model and the traditional AHP model. First, because we are allocating net cost savings, it is possible that some of the priority weights will be negative. This would be the case when the net effect of an investment on a particular activity is to increase the cost of that activity (negative cost savings). Second, we will not normalize the priority weights derived from our ABC model, because we would lose the true cost impact by doing so. For example, suppose activity 1 has a net cost savings of $4,000 under investment A and $1,000 under investment B, while activity 2 has a net cost savings of $10 under investment A and $40 under investment B. Assume both activities are equally important. If we normalize the cost savings for each activity, we would assign a priority of 0.8 to A and 0.2 to B for activity 1 and 0.2 to A and 0.8 to B for activity 2. Thus, the activities would have equal impact on the final decision, even though common sense tells us that a $4,000 savings is much more significant than a $40 savings. To avoid this problem, we preserve the magnitude of the cost savings by not normalizing the priority weights of the investment alternatives.

Example. Suppose management is interested in improving capacity, quality and productivity. They wish to evaluate two new machines for this purpose. Machine A uses a new technology that results in less raw material waste and uses less fuel, but because of its complexity, will require more maintenance and some additional management effort. Machine B does not reduce the amount of raw material usage, but because it uses a different process, the company can purchase cheaper raw material. This, however, will result in additional management effort, since it must be purchased from several different vendors. Machine B also uses more fuel but requires less maintenance than the existing machine. The purchase of these machines will not affect the amount or cost of direct labor.

Management has computed the equivalent annuity (on a monthly basis) for the cost of machines A and B to be \$10,000 and \$8,000 respectively. There are four resource cost pools in the ABC model and management estimates the following monthly cost savings (including capital investment):

Table 4-1. Cost Savings

	Raw Material	Fuel	Management	Maintenance	Capital Investment
Machine A	\$20,000	\$30,000	-\$5,000	-\$15,000	-\$10,000
Machine B	\$50,000	-\$10,000	-\$20,000	\$10,000	-\$8,000

Note that if management used traditional investment analysis, they would use the information in Table 4-1 to conclude that the net monthly cost saving of machine A ($20,000) is lower than that of machine B ($22,000) and thus would choose machine B.

Using AHP techniques, management has developed the following priority weights for strategic goals and activities:

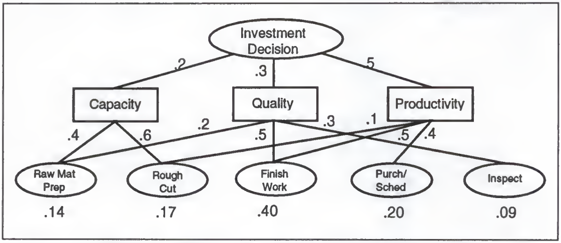

Figure 4-3. AHP Priority Weights for Goals and Activities

The numbers underneath each activity in Figure 4-3 indicate the relative importance to the investment decision of each activity and will be used in both the cost and performance impact models. This represents the first step in our investment analysis. Management has identified five critical activities and estimates resource driver usage under each alternative will be as follows:

Table 4-2. Resource Driver Usage

Invest A/Invest B	Raw Material Preparation	Rough Cut	Finish Work	Purchasing/ Scheduling	Inspection
Raw Material (tons)	100/120				
Fuel (gallons)	0/40	250/250	250/250		
Management (hours)	10/15	5/5	5/5	30/40	10/10
Maintenance (hours)		20/5	15/5		
Cap Inv (machine hrs)	0/74	500/463	500/463		

We can then distribute the cost impact of the resources to the activities as shown in Tables 4-3 and 4-4:

Table 4-3. ABC Cost Allocation for Machine A

Invest A ($1,000)	Raw Material Preparation	Rough Cut	Finish Work	Purchasing/ Scheduling	Inspection
Raw Mat	20 x (100/100)				
Fuel		30 x (250/500)	30 x (250/500)		
Mgt	-5 x (10/60)	-5 x (5/60)	-5 x (5/60)	-5 x (30/60)	-5 x (10/60)
Maint		-15 x (20/35)	-15 x (15/35)		
Cap Inv		-10 x (500/1000)	-10 x (500/1000)		
Total	19.17	1.01	3.15	-2.5	-0.83

Table 4-4. ABC Cost Allocation for Machine B

Invest B ($1,000)	Raw Material Preparation	Rough Cut	Finish Work	Purchasing/ Scheduling	Inspection
Raw Mat	50 x (120/120)				
Fuel	-10 x (40/540)	-10 x (250/540)	-10 x (250/540)		
Mgt	-20 x (15/75)	-20 x (5/75)	-20 x (5/75)	-20 x (40/75)	-20 x (10/75)
Maint		10 x (5/10)	10 x (5/10)		
Cap Inv	-8 x (74/1000)	-8 x (463/1000)	-8 x (463/1000)		
Total	44.67	-4.67	-4.67	-10.67	-2.66

The calculations in Tables 4-3 and 4-4 are based on cost savings (Table 4-1) and driver usage (Table 4-2). For example, for investment A, we know from Table 4-1 that the estimated cost savings in fuel will be $30,000. To allocate these savings to the activities, we use the information in Table 4-2. It shows, for example, that Rough Cut uses 250 out of a total of 500 gallons. Therefore, we will allocate half of the fuel savings to Rough Cut (30,000 x 250/500). We follow the same procedure for all the activities until all the cost savings have been allocated.

We now have the priority weights that we will use to link each investment to the activities in our cost impact model. This is the second step in our investment analysis. We can use the results of the first two steps to create our cost impact model (shown in Figure 4-4). The numbers underneath each alternative in Figure 4-4 represent that alternative's score. The score is obtained by first multiplying the relative importance of each activity (obtained from Figure 4-3 and shown in parentheses) by the ABC cost allocation for each alternative (obtained from Tables 4-3 and 4-4), then summing the results for each alternative. For example, the score for alternative A is calculated as follows:

(0.14 x 19.17) + (0.17 x 1.01) + (0.40 x 3.15) + (0.20 x -2.5) + (0.09 x -.83) = 3.54. Note that the final result favors machine A even though the net cost savings were higher for machine B.

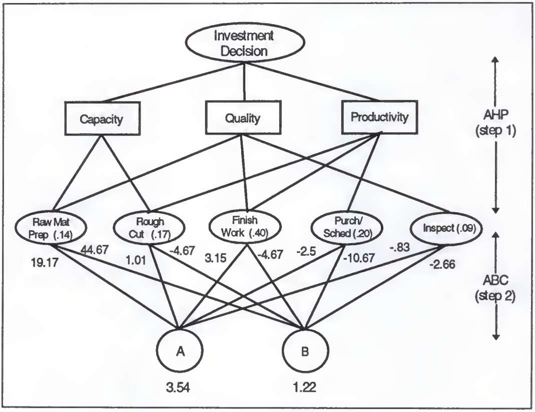

Figure 4-4. Cost Impact for Example

Performance Impact

One of the key features of an activity-based investment analysis is the evaluation of the performance of an activity rather than narrowly focusing on cost. Activity-based investment management links the strategic plan to the activities through quantitative performance measures. It decomposes each of the performance measures into the specific activities pertaining to it. The total impact of changing activities can then be measured in terms of tangible performance measures (Brimson, 1989).

The link from performance measure to activity is a natural result of implementing ABM. Management establishes performance measures based on the information they need to control and improve activities. Performance measures allow management to influence activities that are critical to strategic goals. Thus activities provide a tangible link between operating indices (performance measures) and long-term objectives (strategic goals). Without this link, management is left with "intangible" benefits from long-term goals which they perceive as important but unmeasurable. By analyzing the business process, management can link each performance measure to one or more activities. Our model then relates the investment alternatives to the strategic goals through the activities. Evaluating investments based on their impact on performance measures allows management to quantify "intangible" benefits and make better investment decisions.

The performance impact model links investments to activities through performance measures rather than resources. Strategic goals are still attributes, but our sub-attributes are now activities and performance measures. All the priority weights in this model are derived from pairwise comparisons using AHP techniques. Note that the first two levels of the model were developed earlier in step 1. The development of priority weights linking performance measures to activities and investment alternatives represents the third step in our investment analysis.

Example. Assume management has chosen the following performance measures (shown with the activities they relate to):

Table 4-5. Performance Measures

% waste	fuel/machine hr	% defective	units/mach hr	lead time	# customer complaints
Raw Mat Prep	Rough Cut	Rough Cut	Rough Cut	Purch/Sched	Inspection
Rough Cut	Finish Work	Finish Work	Finish Work		

The relative importance of each performance measure to each activity can be determined by management using AHP techniques (step 3). We will use the same relative weights for activities and goals that we used in the cost impact model (from step 1). We can now use the results of steps 1 and 3 to create the performance impact model for our example, as shown in Figure 4-5. Note that machine A is slightly favored based on performance impact, but is by no means a clear favorite.

Choosing Investment Alternatives

We can now combine the results of our cost and performance models to select the best investment. Note that our models assign a "score" or weighted evaluation to each investment alternative, one for cost and one for performance (a high score in the cost model indicates favorable cost savings). We can use a cost vs. performance graph to help us select the best alternative (see Figure 4-6). On this graph, those investments falling in quadrant III are the most desirable, while those falling in quadrant II would be the least desirable. Note that the cost "scores" must be normalized before imputing them into this graph. For our example, we first normalize the cost scores to .74 for machine A and .26 for machine B. The scores are then plotted on Figure 4-6 and we see that machine A is the better investment, mostly as a result of its cost impact.

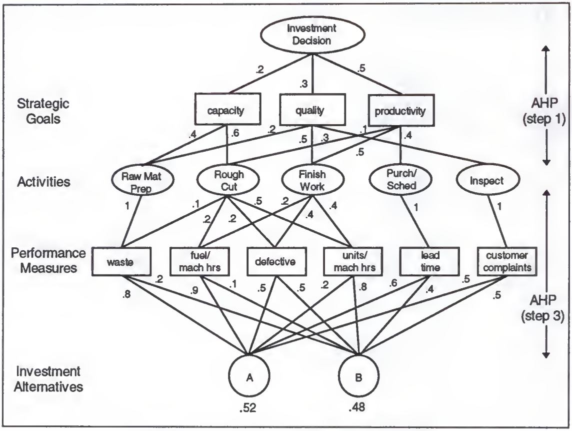

Figure 4-5. Performance Impact for Example

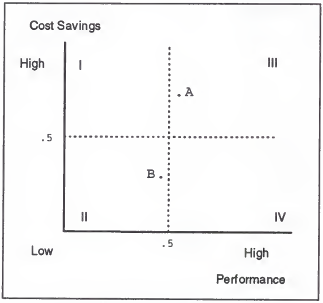

Figure 4-6. Cost vs. Performance

Conclusion

Although the performance impact model uses AHP, a well-established decision technique, it focuses on strategic goals, activities and performance measures. A key to the success of this approach lies in making sure that performance measures do indeed tie into strategic goals. If this is not the case, there is a disconnect between company goals and departmental goals, particularly if performance measures are used to evaluate division performance. As a result, department heads will not be focusing on activities that support company goals and investment options will be selected on the wrong basis.

The example used in this chapter compares two investment alternatives. The underlying assumption is that management has decided to make a capital investment and that each of the alternatives is within management's budget. The model then provides a framework for ranking the alternatives. Note that the model could just as easily accommodate more than two alternatives, as long as each alternative is within the budget. If the budget can accommodate more than one alternative, then management can use the ranking results to choose the best mix of investments.

In developing the cost impact model, we did not directly include the effect of depreciation on overhead. Instead, we used the equivalent annual cost of the initial investment. As long as we are comparing two new investment opportunities, this method works well, since it considers the time value of money. However, if we wish to compare an existing technology with a new technology, we could use depreciation to account for the effect of the initial investment. Of course, the cost impact model will tend to favor the old (existing) technology (as is the case in traditional investment analysis) since older technology will probably have a lower (or zero) depreciation charge. On the other hand, the new technology will most likely be favored in the performance impact model, thus allowing the decision maker to consider the relative merits of non-financial as well as financial criteria.

Although it was not illustrated in our example, it is possible that the cost impact model will assign a negative score to one or more investment alternatives. This would occur when the investment alternative has a negative impact on the most important activities that is not offset by the positive impact on less important activities (even if the net cost impact prior to distribution is positive). When this happens, we can still normalize the scores, retaining the sign of each score, but we must expand our cost vs. performance graph to include negative numbers. Since we are not allowing negative performance scores, only the cost axis would be affected. The result would be to expand regions II and IV into the negative range, without changing the relative desirability of each region (III would remain the most desirable, while II would remain the least desirable).

In order to remain competitive in the future, firms must make investment decisions based on strategic goals. Contrary to traditional investment analysis, the investments that best support these goals may not always be those with the highest financial return. By incorporating activities and strategic goals into investment analysis, management can look into the future, rather than making a decision based primarily on past performance. Traditional financial analysis ranks investments based on net cost savings (or some related measure, such as payback period). Our cost impact model goes beyond this step, by looking at how the net cost savings are distributed among activities. It then ranks the investments according to how they benefit the most important activities (based on strategic goals). As demonstrated in our example, an investment that is superior based on net cost savings may not be the best choice when evaluated on activities and strategic goals. Thus, failure to consider the cost impact on activities and strategic goals may lead to incorrect decisions.

CHAPTER 5
DETERMINISTIC SCHEDULING

Cost Considerations

Scheduling plays an important role in manufacturing as well as in service industries. In the current competitive environment, effective scheduling can be critical for survival in the marketplace. Companies have to meet shipping deadlines to supply Just-in-Time customers, scarce resources have to be used in the most efficient manner and activities have to be organized to insure optimal performance. Activity-based costing can affect scheduling models in several ways. First and most obviously, ABC information can change the value of cost parameters in a scheduling problem. Secondly, ABC can identify schedule-dependent cost drivers that can be optimized using scheduling techniques. Finally, as part of an ABC analysis we can recognize opportunities for cost improvements by focusing on activities that may be improved by better scheduling or using scheduling to minimize the cost of a process.

Before discussing these effects, we offer a word of caution about terminology. Scheduling is commonly described as the optimal allocation or assignment of resources, over time, to a set of tasks or activities. The resources may be machines, people or space and the activities could be steps in a production process, stages in a construction project or tasks at an airport. Activity-based costing measures the cost of resources as they are consumed by activities and cost objects. This common use of terms (resources and activities) can lead to some confusion if we are not careful.

For example, the number of machines is typically used to define the processing environment of a scheduling problem (single machine, parallel machines, machines in series, etc.). The scheduling problem also specifies how jobs are processed on the machines (job characteristics). If the machines represent steps in a production process, they would be defined as *activities* in ABC. On the other hand, if they represent space to be allocated for different activities, they would be considered *resources* in ABC. Likewise, a job in a scheduling problem can be either a cost object or an activity. If the job represents a product undergoing various steps in a production process, then it would be a *cost object* from an ABC perspective. If instead we are assigning several tasks to different people in a shop, each task would represent an *activity* in ABC. Although these differences may not present any difficulty when formulating an abstract scheduling model, they must be carefully considered if we wish to apply the results of the model to a real world problem.

Cost Parameters

Scheduling problems seek to minimize some performance parameter based on given process times (p_j), setup times (s_j) and due dates (d_j). For example, we can minimize makespan, defined as max $\{C_1, \ldots, C_n\}$, where C_j is the completion time of job j, or we can minimize the sum of the completion times, $\sum C_j$, known as the flowtime. If we wish to incorporate a cost parameter, we would minimize the weighted sum of the completion times, $\sum w_j C_j$, or the weighted flowtime. In the first two cases the performance parameters are unweighted ($w_j = 1$), while the third case uses a weighted parameter. Using an unweighted performance parameter implies that all tasks or jobs are equally important. It does not imply that there is no penalty cost associated with suboptimal performance, but rather that the penalty function is the same for all jobs.

Consider a common penalty function, lateness. The lateness of job j is defined as $L_j = C_j - d_j$ and the associated penalty function is shown in Figure 5-1 ($w_j = 1$). If we choose to use the weighted lateness as our performance parameter, then the slope of the penalty function is defined by w_j and the greater the weight, the higher the penalty (see Figure 5-1). By assigning different weights to different jobs, we incorporate the relative cost of lateness and we acknowledge that some jobs are more expensive than others.

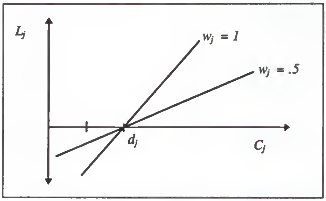

Figure 5-1. Lateness Penalty Function

Because activity-based costing is concerned primarily with the allocation of costs, it will not directly affect those scheduling models whose performance parameter is unweighted. However, even for those models where we are concerned with optimizing performance rather than cost, there is an underlying assumption that optimal performance results in cost savings. For example, if the objective function is to minimize idle time, we are assuming that idle time is a waste of resources (capital), but no attempt is made to assign a dollar value to the wasted resources. If we seek to minimize the number of tardy jobs, we are implicitly minimizing some cost penalty associated with tardy jobs, but again, we are not concerned with the dollar loss associated with tardiness. Although there is in fact a penalty function associated with each of the performance measures, the dollar value of the penalty is not explicitly included in the scheduling model, but is instead used to justify the objective of the model.

Weighted scheduling problems explicitly include cost in the scheduling model through the use of weights. Each job *j* is penalized an amount w_j relative to a performance measure, such as completion time C_j. The value of the penalty weight can be assigned based on some subjectively determined relative importance of the jobs, which may not be based on actual costs, or it can be assigned based on the expected dollar loss that will result from substandard performance. It is the later weighting assignment that is of interest to us, because ABC is particularly well suited to providing these weights.

To see how ABC is better suited to providing the cost weights in a scheduling model, we need only observe that such costs are generally considered indirect costs. For example, the weighted completion time gives an indication of the holding or inventory costs associated with the schedule (Pinedo, 1995, 13). A traditional accounting system would allocate holding costs based on volume, so that each job received an equal amount, w. An ABC system, on the other hand, could assign holding costs using non-volume drivers such as square footage or dollar value. This would result in different costs (w_j) for different jobs based on their usage of the holding activity. Weighted tardiness provides another example. Here the weight is the penalty associated with a late delivery. The cost of that penalty will likely vary from job to job, but that fact will not be captured by a traditional accounting system. An ABC system, however, could provide this information by identifying those activities and costs associated with late delivery and assigning the cost of those activities to each job based on an appropriate cost driver.

Although scheduling models have always recognized that penalty costs may be different from job to job, the values of the weights are usually determined subjectively, for instance, by assessing the relative "importance" of a job. This was necessary because traditional cost accounting systems offered no help in this matter, since overhead allocation was based on volume and did not discriminate between job types. With ABC it may be possible to extract the information from the cost system, thus providing a less arbitrary assignment of weights and a more accurate scheduling model.

Schedule Dependent Cost Drivers

Even if a scheduling model does not explicitly consider cost through the use of weights, it may still be influenced by ABC. Such is the case when the cost driver used to allocate resource or activity consumption can be improved through better scheduling. In other words, if the cost driver used by the ABC system to allocate cost is schedule-dependent, then we may use a scheduling model to improve the performance of the process. Likewise, the ABC analysis may show that a schedule-dependent driver should be used to allocate activity costs, highlighting an activity that could benefit from scheduling optimization.

Note that if the cost driver used by the ABC system is not schedule-dependent, then improvements gained through schedule optimization may not be reflected in the accounting system. Hedge and Nagurajan (1992) looked at this problem as it relates to setup time. They suggested that an ABC analysis might reveal that setup costs are high, thus motivating the shop floor to reduce the number of setups in order to reduce costs. On the other hand, the production engineers seek to reduce setup costs by reducing setup times. This apparent conflict is due to the fact that cost allocation is based on the number of setups, while the engineering analysis implies that setup time and not number of setups, is the appropriate cost driver for setup costs. If setup time is the significant cost driver, then the ABC system should reflect this by using setup time rather than number of setups to allocate costs. The shop floor will then be motivated to reduce setup time and will not be adversely impacted by an increase in the number of setups. In reality, both cost drivers may be appropriate and should be incorporated into the cost accounting system.

Setup Time

As an example, consider the well known scheduling problem of minimizing sequence dependent setup times. As noted above, setup time may be used to allocate the costs of the setup activity to the products. Given this allocation, the plant manager would seek to improve the process by reducing setup time. If the setup times are sequence-dependent, we wish to minimize the total setup time and we have the following problem:

$$\text{Min } \sum s_{ij}$$

where s_{ij} is the time required to setup from job i to job j. This problem has been well studied and is equivalent to the traveling salesman problem, which is NP-complete, but can be solved with heuristic methods (see, for example, Johnson and Montgomery, 1974, p. 339).

This is a case where ABC did not directly affect the scheduling problem, but it did provide an incentive for the type of scheduling model to be used. Where a traditional cost system would not even recognize setup time as a cost driver, the ABC system would, provided of course that setup costs are indeed dependent on setup time. By using setup time in the cost accounting system two things are accomplished. First, as a result of the cost being tied to setup time, an incentive is created to minimize setup time. Secondly, the savings achieved by scheduling techniques will be reflected in the financial records and can be measured in dollars and cents. This will validate the benefits of efficient scheduling.

Number of Setups

Another cost driver for the setup activity might be the number of setups required by a product (a batch-level activity). This might be the case if each setup had the same cost regardless of the type of product. In this case the process would be improved by minimizing the number of setups subject to some other performance requirement such as due date or flowtime. For example, if we are concerned with due dates we would have the following problem:

$$\begin{aligned} &\text{Min} \quad \sum x_j \\ &\text{s.t.} \quad c_i \le d_i \end{aligned}$$

were x_j is the number of setups required to process all the jobs of type *j*, c_i is the completion time of job *i* and d_i is the due date of job *i*. We assume that there are several similar jobs (all type *j*) which could be processed as a batch, with only one setup required per batch. This of course would minimize the number of setups provided we had no other constraints. In our example, however, we make the more realistic assumption that the due date is also important, which may affect the order in which we process the batches, or even which jobs we can include in a batch and consequently the number of batches and setups. Again, this is an example where the motivation for the scheduling problem arises from the cost driver identified in the ABC system.

Cost Improvements

Optimizing the sequence of activities in a manufacturing process is a classical scheduling problem. While ABC may not change the objective of this problem, an ABC analysis can help identify activities and define the process. This information can then be used to build a scheduling model and optimize performance. Even the performance of an individual activity may be optimized through scheduling techniques and this fact may be recognized in the ABC analysis. This is the essence of activity-based management. Once we have identified the activities, we seek to improve the activities and the process rather than simply trying to manage the costs. In some cases, we can also improve the cost of a process through better scheduling.

Cost Minimization

ABC traces the cost of resources to activities and focuses attention on the cost of activities. This suggests the possibility of minimizing the total cost of activities (the process cost) as a scheduling objective. For example, consider the case where a production line has two machines that accomplish the same task (activity). Machine A is completely automatic and only requires periodic checking. Machine B is older and requires a full-time operator. The ABC system could provide the cost per item of each machine, say w_A and w_B. Our objective is to minimize the total cost of production and we can do this by optimizing the scheduling of products (jobs) through the two machines:

$$\text{Min } \sum w_j x_j$$

where x_j is the total number of jobs assigned to machine j. A similar situation would arise if we had several subcontractors available to perform a variety of tasks and each subcontractor has a different cost per task.

Without any constraints, the trivial solution would be to process all the jobs on the machine with the lowest per unit cost (w_j). But in reality we have the typical constraints, such as due date, completion time and lateness. If we are concerned with due dates for example, we would have the following problem:

$$\begin{aligned} &\text{Min } \sum w_j x_j \\ &\text{s.t.} \quad c_i \le d_i \end{aligned}$$

where c_i is the completion time of job i on machine j and d_i is the due date of job i. Note that the problem could be modified for different cost drivers. For example, if time is the critical cost driver, w_j could be the cost per hour of machine j and x_j could be the total number of hours spent on machine *j*. This might be the case if the ABC system uses machine hours as the cost driver. Letting t_{ij} be the number of hours job *i* takes on machine *j*, we can formulate the problem as

$$\begin{aligned} &\text{Min} \;\; \sum w_j t_j \\ &\text{s.t.} \quad c_i \le d_i \end{aligned}$$

where $t_j = \sum_i t_{ij}$ is the total time spent on machine j. Our goal is to find a schedule that meets our due date constraint while minimizing cost.

Conclusion

The benefits of optimal scheduling are widely accepted but poorly defined. In most cases benefits and costs are couched in subjective terms such as “goodwill” or “penalty” that offer no measurable results. By incorporating scheduling parameters in the cost accounting system, ABC can allow us to objectively measure the benefits of better scheduling. If the cost drivers used by the ABC system to allocate resources to activities and activities to products are schedule-dependent, then the benefits of an optimal schedule will be reflected in the cost system. This will in turn provide a tangible, verifiable incentive for the manufacturing managers to optimize scheduling. In addition, the increased detail provided by ABC offers the opportunity to incorporate real cost parameters in scheduling models, thus creating a more realistic model.

CHAPTER 6
COST/SCHEDULE ANALYSIS

Traditional Model

Cost/Schedule analysis is based on the relationship between cost and time for a project. Given the normal duration of each activity and the precedence relationships between the activities, we can construct a feasible schedule. Typically we start with a project network showing the activity precedence, with directed arcs representing the activities and nodes representing the beginning and end of activities. The network starts with one unpreceded node and ends with one unsucceeded node. It is labeled so that for every arc (i,j), $i < j$. We represent an activity by (i,j), denote its duration time as t_{ij} and its start time as T_i. We can use the network to calculate the total duration of the project, which is determined by the length of the longest path of activities, referred to as the critical path. If any activities on the critical path are delayed, the duration of the entire project will be delayed.

The traditional cost/schedule model assumes that activity duration can be shortened as some nondecreasing function of cost. In other words, the longer the activity duration, the less expensive the cost of the activity. Thus, if we wish to compress the total duration of the project, the model assumes that total direct costs will increase. For example, we can complete the project earlier, but we may have higher labor costs as a result of subcontracting the work or paying overtime. On the other hand, the model assumes that total indirect costs, such as rent and utilities, will increase with time, so the longer the project lasts, the greater our total indirect costs. Thus, we seek the optimal project duration so that the sum of direct and indirect costs is minimized.

The initial problem deals only with direct costs and consists of finding the least cost way of reducing activity duration times in order to meet a fixed project duration, λ. The simplest model assumes a linear cost-time relationship ($a_{ij} - b_{ij}t_{ij}$) where a_{ij} is the maximum direct cost of performing the activity in the shortest possible time and b_{ij} is the cost per unit of time reduction. For each activity we specify an upper bound, t^n_{ij} (known as the normal time) and a lower bound, t^c_{ij} (known as the crash time). The minimum total direct cost of a project of duration λ can be formulated as follows:

$$\begin{array}{lll} \text{Min} & \sum_{(i,j)\in A} (a_{ij} - b_{ij}t_{ij}) & & \text{D}(\lambda) \\ \text{s.t.} & T_i + t_{ij} - T_j \le 0 & \forall (i,j) \in A & \\ & T_n - T_1 \le \lambda & & \\ & t^c_{ij} \le t_{ij} \le t^n_{ij} & \forall (i,j) \in A & \end{array}$$

where T_{ij} is the realization time of event i,

t_{ij} is the duration of activity (i,j),

λ is the project duration (completion time),

t^c_{ij} is the crash duration of the activity and

t^n_{ij} is the normal duration of the activity

The purpose of this linear program is to find the optimal realization times and duration times for each of the activities given the project duration, λ. We can use D(λ) to find the minimum direct cost for each λ between T_n (min) based on crash times and T_n (max) based on normal times. This will allow us to construct the direct cost vs. duration curve for the project which will be a nonincreasing convex function of time. We will call this the activity cost curve, since it is based on the cost of the activities. Indirect costs (assumed to be a nondecreasing convex function of time) must be added to this activity cost curve to obtain the total cost curve. The total cost curve for the project will be convex and will have a minimum at λ^*. This will be the project duration that will result in the least total cost.

ABC Model

Direct project costs include labor, supplies and equipment, while indirect costs (also referred to as overhead) include such items as rent, interest, utilities and other costs that normally increase with the length of the project but are not assigned to activities. Activity-based costing suggests that we should allocate indirect costs at the activity level and not necessarily as a function of time. For cost/schedule analysis, only those indirect costs that vary with time will affect the optimal schedule since we are seeking to optimize cost as a function of time. Costs that are fixed with respect to time will increase the total cost of an activity, but not the cost of compression. Nevertheless, ABC will identify other cost drivers that could be optimized. Optimizing these other drivers would change not only the total cost of the project, but it might also change the cost of compression for one or more activities, which would result in a different cost vs. time function.

Because time is the cost driver of interest in the cost/schedule model, we will assume that there are direct costs that can be allocated based on time, just as the traditional model does. The difference lies not in the allocation basis, but in the consumption of indirect costs by activities. Using ABC, we will be able to allocate some (or all) of the indirect costs to those activities that consume the overhead resources using a variety of cost drivers, not just time. As mentioned previously, overhead will consist of a fixed portion that does not vary with time, which we will denote as c_{ij} and a variable portion, d_{ij}, which represents the cost per unit time of indirect resources. For simplicity, we will assume a linear relationship $(c_{ij} + d_{ij}t_{ij})$ for the indirect costs assigned to each activity, as is normally done in ABC systems.

Having allocated indirect costs to each activity, we must consider how the indirect costs will affect the cost vs. time function. We will assume, as we did originally, that the direct cost vs. duration relationship for each activity is linear and decreasing. We will also assume that the indirect cost vs. duration relationship for each activity is linear and increasing. Thus our new objective function will be

$$\text{Min} \sum_{(i,j)\in A} (a_{ij} - b_{ij}t_{ij}) + (c_{ij} + d_{ij}t_{ij})$$

For each activity, if $b_{ij} > d_{ij}$, the cost vs. duration relationship will be linear and decreasing, as it is in the original model, but the cost per time unit of compression will be decreased. However, if $b_{ij} < d_{ij}$, the cost vs. duration relationship will be linear and increasing and if $b_{ij} = d_{ij}$, the cost of activity (i,j) will be fixed over the length of the project. Thus we see that ABC can radically change the basic assumption of the traditional cost vs. schedule model that compression of activity duration always increases cost.

Although compressing the duration of an activity may indeed increase direct costs, allocating indirect costs to the activity may reverse the total cost vs. time relationship, so that for some activities, compression of duration can lower total cost. Thus, there may be activities that we wish to make as short as possible, which is never the case in the traditional model. Even for those activities where the cost vs. time relationship remains decreasing, the compression cost per unit time is decreased. By tracing the indirect costs to those activities that require them, we can get a more accurate picture of the cost behavior of the activities with respect to time, which leads to better project scheduling decisions.

The objective is to minimize total cost. The traditional model only minimizes direct costs by compressing those activities that have the lowest direct cost per unit of time reduction (b_{ij}). It completely ignores the link between activities and indirect costs. The ABC model on the other hand, captures the relation between activities and indirect costs and minimizes total cost, not just direct cost. Some activities that appear to have a high cost per unit time of reduction in the traditional model, may in fact have a low total cost per unit time of reduction in the ABC model. Even two activities that have the same cost per unit time of reduction in the traditional model may end up with completely opposite cost vs. time functions in the ABC model. This is because one activity may consume very few indirect resources ($b_{ij} > d_{ij}$), so that its cost vs. time function remains decreasing (Figure 7-1), while the other may consume large amounts of indirect resources ($b_{ij} < d_{ij}$), so that its cost vs. time function becomes increasing (Figure 7-2). This is possible because ABC does not distribute the indirect costs evenly across all activities as is implicitly assumed in the traditional model.

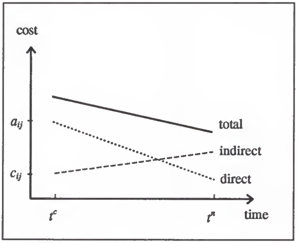

Figure 7-1. Activity Cost When $b_{ij} > d_{ij}$

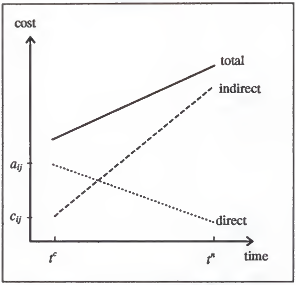

Figure 7-2. Activity Cost When $b_{ij} < d_{ij}$

There may still be some indirect costs which cannot be reasonably traced to activities, such as interest on borrowed money. These project level costs would be treated in the same manner as all indirect costs are treated in the traditional model. They must be added to the activity cost curve in the final step of the analysis in order to find the optimum project duration, λ^*. But even if some indirect costs are not traced to activities, the ABC model still provides a more accurate picture of cost behavior. By using ABC to rationally allocate indirect costs to each activity in the project, we are able to make a better informed decision about the cost of reducing the project completion time.

Conclusion

The cost vs. schedule model provides a classical example of how a model has been created to fit the available accounting data. With traditional cost accounting lacking the appropriate details to properly allocate indirect costs, the decision makers were forced to use a primitive model. Although ABC does not radically change the mathematical formulation of the cost/scheduling model, the impact can be significant. Including the traceable indirect costs for each activity can dramatically alter the cost vs. time function and thereby change the critical path of the project, which will in turn change the order in which activities are crashed. Thus the results of the ABC decision may differ from the traditional model.

CHAPTER 7
PRODUCT MIX

Traditional Model

One of the most commonly used operations research models is the product mix model. This model is usually formulated as a linear program with the objective of maximizing profit for a given set of products and resource constraints and is typically used to illustrate the application of linear programming. The decision variables, x_i, represent the amount of product i to be produced under a given set of resource constraints.

Traditionally the objective function considers one of two cases: the short-term contribution margin (which excludes fixed overhead costs) and the long-term full-absorption margin (which includes fixed overhead as a percentage of the volume). The short-term case can be formulated as follows:

$$\begin{aligned} \text{Max} \quad & \sum_i p_i x_i - (m_i + l_i) x_i \\ \text{s.t.} \quad & \sum_i m_i x_i \le M \\ & \sum_i l_i x_i \le L \end{aligned}$$

where p_i is the sales price, m_i is the direct material cost and l_i is the direct labor cost. The long-term case is formulated as:

$$\begin{aligned} \text{Max} \quad & \sum_i p_i x_i - (m_i + l_i + f_i) x_i \\ \text{s.t.} \quad & \sum_i m_i x_i \le M \\ & \sum_i l_i x_i \le L \end{aligned}$$

where f_i is the overhead rate per unit. The model suffers from several shortcomings. First, in the case of marginal cost, the assumption is that the indirect cost are fixed and unaffected by the decision parameter. Second, in the case of full-absorption costing, all indirect costs are assumed to be proportional to production volume (x_i). Clearly, neither of these two choices is entirely valid and the truth is that while some overhead does vary with production volume and cannot be ignored (even in the short-run) other indirect costs vary with complexity, a parameter captured by an ABC system, but ignored in a traditional cost system. This leads us to the third shortcoming of the model, the fact that it does not accommodate details that may be available from an ABC system. This is an excellent example of how the cost accounting system can influence a decision model. Since the traditional cost accounting system did not provide the variety of cost drivers that can be found in an ABC system, the operations research model was limited as well.

Volume-Related Fixed Costs

ABC recognizes that not all "fixed" cost is really fixed, but may in fact vary in the long term or with other cost drivers besides volume. Malik and Sullivan (1995) try to capture the long-term aspect by modeling fixed costs as step functions of volume. Their model assumes that each resource *j* has a maximum volume of product *i* that can be produced and that the cost to increase this capacity is k_{ji}. They formulate the problem as follows:[1]

---

[1] We have revised some of the notation used by Malik and Sullivan to be consistent with the notation we use in the rest of this paper.

$$\begin{aligned}
\text{Max} \quad & \sum_i \left\{ p_i x_i - (m_i + l_i)x_i - \sum_j k_{ji} \left\lceil {x_i}\big/{n_{ji}} \right\rceil \right\} \\
\text{s.t.} \quad & \sum_i m_i x_i \le M \\
& \sum_i l_i x_i \le L \\
& \sum_i k_{ij} \left\lceil {x_i}\big/{n_{ji}} \right\rceil \le O_j
\end{aligned}$$

where n_{ji} is the capacity (in units) of resource j for product i and O_j is the limiting constraint for resource j. While this model is a definite improvement over the traditional model, it too has some problems.

First, the notation used by Malik and Sullivan is confusing, because they refer to resources being consumed by products, which is the traditional view of cost allocation. If the model is based on ABC information, they should refer to *activity j* (rather than resource *j*). Second, the model only considers those indirect costs that can be allocated with volume-related cost drivers. It ignores the indirect costs that vary with non-volume-related cost drivers (those that vary with complexity rather than some function of volume). Finally, by summing the incremental activity (resource) step costs for each product separately, the model assumes that the capacity of each activity (resource) is divided into product capacities which are mutually exclusive. This might lead to incorrect results.

For example, consider a case similar to the one suggested by the authors (p. 172): a certain shop floor area can accommodate six machines for product 1, so k_{j1} would be one sixth of the total rent/cost (k_j) for the area, or $k_{j1} = k_j/6$. The same area can only accommodate three machines for product 2, so $k_{j2} = k_j/3$. Product 1 machines can produce a maximum of 100 units per period, while product 2 machines can produce up to 300 units per period, so $n_{j1} = 100$ and $n_{j2} = 300$. Now suppose we produce 80 units of product 1 and 500 units of product two, so we need one machine for product 1 and two machines for product 2. Clearly, we do not need to increase the shop floor area to accommodate these three machines, so the total cost of the shop floor resource will be k_j. However, the proposed model would calculate the shop floor cost as follows:

$$\frac{k_j}{6}\left\lceil \frac{80}{100} \right\rceil + \frac{k_j}{3}\left\lceil \frac{500}{300} \right\rceil = \frac{5k_j}{6}$$

A better way to model the shop floor cost would be the following:

$$k_j \left\lceil \sum_i \frac{a_{ji}}{m_{ji}} \right\rceil$$

where a_{ji} is the number of product i machines used on the shop floor (activity j) and m_{ji} is the capacity of the shop floor in terms of machine i. The number machines used is a step function of quantity:

$$a_{ji} = \left\lceil \frac{x_i}{n_{ji}} \right\rceil$$

Thus the total cost of the shop floor becomes

$$k_j \left\lceil \frac{1}{6} + \frac{2}{3} \right\rceil = k_j$$

which is the actual cost of the shop floor, as shown earlier.

ABC Model

In order to capture both the volume-related indirect costs and non-volume-related indirect costs allocated by an ABC system, we must use a more general model for indirect costs:

$$k_j \left\lceil \sum_i \frac{a_{ji}}{m_{ji}} \right\rceil \qquad (1)$$

where a_{ji} is the amount of activity *j* driver consumed by product *i* and m_{ji} is the capacity of activity *j* for product *i*. We can now consider three cases: the cost driver is volume (aji = xi), the cost driver is volume-related [aji = fj(xi)] and the cost driver is not volume-related (aji is not a function of xi).

Cost driver is volume. In this case $a_{ji} = x_{ji}$ (the volume of product *i* using activity *j*) and $m_{ji} = n_{ji}$. This gives us the long-term step function cost of each activity. Note that if product *i* does not use activity *j* we simply let $x_{ji} = 0$. With volume as the cost driver model (1) becomes

$$k_j \left\lceil \sum_i x_{ji} / n_{ji} \right\rceil \tag{2}$$

Cost driver is volume-related. In this case $a_{ji} = f_j(x_i)$. For example, if the cost driver is the number of setups, we can easily relate it to the volume through batch size:

Let a_{ji} = number of setups on machine *j* for product *i*

s_{ji} = batch size of product *i* on machine *j*

then $a_{ji} = \frac{x_{ji}}{s_{ji}}$ and $f_j(x_i) = \frac{x_{ji}}{s_{ji}}$

Also m_{ji} = maximum number of batches of product *i* on machine *j*, so

$n_{ji} = m_{ji} \times s_{ji}$ = maximum volume of product *i* on machine *j*

So model (1) can be put in the same form as (2)

$$k_j \left\lceil \sum_i \frac{(s_{ji})(a_{ji})}{(s_{ji})(m_{ji})} \right\rceil = k_j \left\lceil \sum_i \frac{x_{ji}}{n_{ji}} \right\rceil$$

Cost driver is not volume-related. If the cost driver is related to complexity instead of volume, then it is "fixed" over all ranges of volume. This implies that $f_j(x_i) = 0$ or that n_{ji} is so large that x_{ji}/n_{ji} is always less than one. In this case model (2) is of little use, but model (1) still works. For example, suppose the cost driver is the number of engineering change orders or maybe the scheduling hours spent on each product. In both cases the volume of a particular product does not effect the total indirect cost, but it still varies from product to product based on non-volume cost drivers.

In order to capture the information provided by all the ABC cost drivers we must use the following product mix model:

$$\begin{aligned}
\text{Max} \quad & \sum_i \left\{ p_i x_i - v_i x_i - \sum_j \left[k_j \left[\sum_i \frac{a_{ji}}{m_{ji}} \right] \left({}^{a_{ji}}\!\big/_{a_j} \right) \right] z_i \right\} \\
\text{s.t.} \quad & \sum_i m_i x_i \le M \\
& \sum_i l_i x_i \le L \\
& k_j \left[\sum_i \frac{a_{ji}}{m_{ji}} \right] \le O_j
\end{aligned}$$

where v_i = variable costs of product j (cost driver is volume)

$a_j = \sum_i a_{ji}$ = total amount of driver j consumed for the period

$$z_i = \begin{cases} 1 \text{ if product } i \text{ is produced} \\ 0 \text{ otherwise} \end{cases}$$

this allows us to incorporate not only the volume-related ABC drivers, but the non-volume-related ones as well. Note that the last term of the objective function represents the portion of "fixed" or indirect cost assigned to product i (F_i). Of course, the portion of F_i that is not volume-dependent is only an approximation based on the expected cost of activities and estimated driver usage (which can be derived from the ABC system), but it still provides a more realistic estimate of the total effect of including product i in the product mix. The problem can be solved as a mixed integer program similar to the example given by Malik and Sullivan.

Conclusion

By considering all the information provided by an ABC model we can improve the traditional product mix model in several ways. First, we can obtain better information about the product costs. This alone improves the accuracy of the model, but does not address the problem of how to handle "fixed" costs. A second improvement can be achieved by incorporating the long-term variability of "fixed" costs using a step function of volume. This creates a more useful model, that can be applied to both short-term and long-term decisions, but fails to include those indirect costs that do not vary with volume. Finally, we can create a more general model that includes non-volume-related cost drivers that are fixed over volume but vary from product to product. This general approach allows us to take full advantage of the information provided by the ABC system, incorporating one of the key aspects of ABC, the accurate tracing of indirect costs.

The ABC model presented in this chapter highlights the advantage of ABC over traditional cost accounting systems. By tracing indirect costs to activities, we are able to understand the true nature of the business process and use the most appropriate drivers to allocate costs to products. The activities become the focus of the cost analysis and this is reflected in the product mix model through the use of driver capacity, rather than volume capacity, to measure the impact of products on fixed costs. The result is a more accurate and realistic model.

CHAPTER 8
BREAK-EVEN ANALYSIS

Traditional Model

Break-even analysis is based on the observation that some production costs are fixed with regard to the production volume, while others depend on or vary with volume. Break-even analysis seeks to determine the minimum volume required to cover both fixed and variable costs based on a given sales price. For a single item, the break-even point in units (x) is given by

$$BE(x) = \frac{F}{P - V}$$

where F is the total fixed cost, P is the selling price per unit and V is the variable cost per unit. Note that P-V is often referred to as the contribution margin, since this is the portion of sales that is available to contribute towards fixed costs. The break-even point in dollars (\$) is given by

$$BE(\$) = \frac{F}{1 - {}^{V}\!/_{P}}$$

These formulas are based on certain assumptions. First, both the revenue and cost functions are linear, a simplification that may not be valid in all cases. Second, the variable cost component is based on only one cost driver, namely production volume. Although this may work for a single-item model, it is a serious flaw in a multi-product environment where different products consume resources in different proportions based on a variety of cost drivers.

In reality the single-item break-even formulas are of little use, since very few companies have only one product. Instead, we must use a multi-product analysis and we must be careful in our determination of the variable and fixed components of cost. This is where activity-based costing can be most helpful. The traditional multi-product break-even point in dollars is given by

$$BE(\$) = \frac{F}{\sum_i \left(1 - V_i/P_i\right) w_i}$$

where w_i is the percent of total sales for product *i*. The multi-product model is based on the product sales volume and the denominator represents the weighted average contribution margin. This method relies on the fact that each product will contribute F_i to the fixed cost as follows:

$$F_i = \frac{P_i - V_i}{P_i}\left(S \cdot w_i\right)$$

where S is the total sales, $\left(S \cdot w_i\right)$ is the portion of total sales attributable to product *i* and $\frac{P_i - V_i}{P_i}$ is the percent of each dollar from product *i* sales that can be contributed to fixed costs (percentage contribution margin). In order to cover the total fixed cost, we must have

$$\sum_i F_i = F$$

and thus we arrive at the multi-product break-even formula. Of course, if the sales volume changes, the break-even point changes as well. The number of units of each product that is required for break-even sales is also based on the sales volume:

$$BE(x_i) = \frac{BE(\$) w_i}{P_i}$$

A similar model can be derived using sales mix (number of units) as the weighting factor, where w_i is the percentage product *i* units sold.

The problem with the traditional models is the assumption that fixed costs are somehow related to the sales volume or sales mix, which is difficult to justify. Granted, we will by necessity cover fixed costs with the contribution margin provided by those products we sell, but the reverse might not be true. That is, we cannot assume that if we maintain a certain sales mix that our fixed costs will be unchanged. This is because using a single cost driver to determine the contribution margin makes it unlikely that our results will be accurate or meaningful. Without the more detailed cost assignment provided by ABC, we will not have a clear picture of the behavior of costs that may vary with non-volume-based drivers such as batch costs. It is not uncommon for product costs and therefore contribution margins, to change significantly under ABC, which in turn would change the break-even analysis.

Traditional break-even analysis ignores the cost of added support resources needed by incremental or special order items. These items appear to have high contribution margins under a traditional cost system because the system fails to properly trace the added resources needed to support these items. Instead, the cost of the additional resources is lumped into “fixed” costs and allocated across all products, based on production volume. Using the incorrect contribution margin results in a break-even product mix that encourages the production of special order items. Unfortunately, increasing the volume of these items only leads to higher “fixed” costs, since those resources classified as “fixed” with regard to production volume are not fixed with regard to other cost drivers.

Simply using ABC to obtain a more accurate contribution margin is not enough. The traditional multi-product model falls short in another area. For a break-even analysis, the distinction between fixed and variable costs is made at the product level. If we have only one product, there will be no difference between traditional costing and ABC, since only one product is available to cover all the costs, both fixed and variable. However, Metzger (1993) suggests how ABC can improve the accuracy and relevance of multi-product break-even analysis. The traditional model only traces volume-based (variable) costs to each product, classifying all other costs as fixed and assumes that all products contribute to fixed costs in proportion to their sales volume. The ABC model does not make this assumption. Instead, it traces non-volume-based (fixed) costs to each product line. These are costs that are fixed with respect to individual units, but vary from product to product. The break-even analysis can then be performed in terms of the variable costs vs. fixed costs assigned to each product. The results will be more accurate, since we are no longer making the assumption that different products consume fixed costs in proportion to their sales volume. Rather, we are using relevant cost drivers to assign these fixed cost to each product line, thus computing more accurate break-even quantities.

In our model we trace all fixed costs to product lines (instead of only "traceable" fixed costs as suggested by Metzger) because the object of break-even analysis is to determine the product mix that best covers all costs. To make long-term decisions about product mix we also must know the product's contribution (or real profitability) when we have distributed the fixed cost to the individual products or product lines (Bakke and Hellberg, 1991). Excluding some costs, such as “plant sustaining” costs, ignores the basic break-even formula (Fixed Costs = Variable Costs - Sales) and fails to provide the product mix needed to cover all costs over the long-run. By applying full absorption costing, ABC can provide a more meaningful assignment of total costs for long-term break-even analysis.

ABC Model

Our model is based on the fact that the ABC system allocates fixed costs to each product based on the product's demand for activities. The amount of total fixed cost (F)

consumed by each product is F_{Pi}, where $\sum_i F_{Pi} = F$. We can then use this information to obtain the break-even quantity for each product:

$$BE(x_i) = \frac{F_{Pi}}{P_i - V_i}$$

so the total break-even quantity is simply $BE(x) = \sum_i x_i$. The break-even dollars are given by

$$BE(\$) = \sum_i \frac{F_{Pi}}{\left(1 - {V_i}/{P_i}\right)}$$

The advantage of this method is that it is based on a rational, detailed allocation of fixed and variable costs, rather than an arbitrary assignment of fixed costs based on sales volume or sales mix.

In ABC we first trace fixed costs to the each activity *j*, then allocate the cost of the activity to each product *i* based on the consumption of activity drivers (*a*). Let F_{Aji} be the amount of activity *j* fixed cost consumed by product *i*. Then $F_{Aj} = \sum_i F_{Aji}$ is the total amount of fixed cost assigned to activity *j* and $F_{Pi} = \sum_j F_{Aji}$ is the total amount of fixed cost allocated to product *i* (note that the total fixed cost is $F = \sum_i F_{Pi} = \sum_j F_{Aj}$). Let the quantity of activity *j* driver consumed by product *i* be a_{ji}. Then $a_j = \sum_i a_{ji}$ is the total amount of activity *j* driver used for the period. Then we can compute the amount of activity *j* fixed costs assigned to product *i* as follows:

$$F_{Aji} = F_{Aj}\left({a_{ji}}/{a_j}\right)$$

and the break-even point in terms of dollars can be determined from the total amount of fixed cost allocated to each product:

$$BE(\$) = \sum_i \sum_j \left[\frac{F_{Aj}\left({a_{ji}}/{a_j} \right)}{\left(1 - {V_i}/{P_i} \right)} \right]$$

The break-even point in units is

$$BE(x_i) = \sum_j \left[\frac{F_{Aj}\left({a_{ji}}/{a_j} \right)}{(P_i - V_i)} \right]$$

Example

Consider a company that produces three products: 1,000 units of A, 500 units of B and 2,500 units of C . Suppose that each unit of A consumes \$1 of direct labor and \$5 of materials, each unit of B consumes \$2 labor and \$3 of materials and each unit of C consumes \$1 of labor and \$3 of materials. In addition, there are overhead expenses associated with machining (\$10,000), production scheduling (\$2,000), material handling (\$5,000), warehousing (\$3,000) and inspection (\$1,000). Since the machining costs vary with the number of units, they will be included in the variable cost of each unit (assume they are allocated based on machine hours, which is proportional to volume) while production scheduling, material handling, warehousing and inspection costs are classified as fixed. Based on past experience, the overhead allocation rate for machining is \$2 per hour. Suppose each unit of product A requires 1 hour of machining, product B requires 3 hours and product C requires 1 hour. Then the total variable cost for each product would be \$8 for A, \$11 for B and \$6 for C and the fixed costs would be \$11,000. The traditional break-even model assumes that each product will contribute to the fixed costs in proportion to its sales w_i. In our example w_A is 30%, w_B is 20% and w_C is 50%, so we assume that each of the products will cover fixed costs based on that proportion. If product A sells for $15, product B for $20 and product C for $10, then the break point (in sales $) is $11,000/.43 = $25,581. In terms of units, we must sell 512 units of A, 256 units of B and 1,279 units of C for a total of 2,047 units.

But the assumption that the products consume fixed costs in proportion to sales is not valid because fixed costs may not be used in the same proportion as sales. Let us use ABC to allocate the fixed costs to each product line based on the consumption of activities, a much more rational way to determine how each product should contribute to the total fixed costs. Suppose we use the following cost drivers for the fixed costs in our example:

Table 6-1. Cost Driver Consumption

Activity	Cost Driver	Product A	Product B	Product C	Total
Prod. Sched.	# batches	10	20	10	40
Mat. Handling	# parts	3	5	2	10
Warehouse	square feet	1500	1000	1500	4000
Inspection	# inspections	1000	1500	2500	5000

Based on the consumption of cost drivers shown above, we would allocated the fixed costs to the products as follows:

Table 6-2. Allocation of Fixed Costs to Products

Activity	Product A	Product B	Product C	Total
Prod. Sched.	500	1000	500	2000
Mat. Handling	1500	2500	1000	5000
Warehouse	1125	750	1125	3000
Inspection	200	300	500	1000
Total	3325	4550	3125	11000

This allocation shows that product A is responsible for about 30% of the fixed costs, product B is responsible for about 42% and product C is responsible for about 28% (compare this to the sales ratios computed earlier). Using the ABC formula for the break-even point we obtain

$$BE(\$) = \frac{3325}{\left(1-\frac{8}{15}\right)} + \frac{4550}{\left(1-\frac{11}{20}\right)} + \frac{3125}{\left(1-\frac{6}{10}\right)} = \$25{,}049$$

Based on units, we need to sell 475 units of product A, 506 units of product B and 781 units of product C, for a total of 1,762 units. Although our total sales number is not much different from the value obtained using the traditional break-even analysis, the product mix is significantly different. This is because the traditional analysis is putting the burden of fixed costs on the high-volume product, regardless of how the fixed costs are incurred. The result is that the high-volume product is subsidizing the low-volume, complex product. The ABC method corrects this by requiring each product to cover its own portion of fixed cost.

Step Function Fixed Costs

Previously we had mentioned that the assumption that revenues and costs are linear may not be appropriate. Although in most cases this simplification is adequate, an ABC analysis may reveal a significant cost driver that is fixed only over a certain range. For example, personnel salaries in a department may be fixed in the short term given a certain demand on resources, but if that demand increases or decreases significantly, then more or less people might be needed for the same activity. Although these costs are fixed with respect to production volume, they are still allocated to products using a non-volume-related activity driver, such as number of purchase orders in the purchasing department or number of maintenance calls in the maintenance department.

Usually such costs are modeled as step functions of production volume, which succeeds in capturing the long-term variability, but fails to incorporate non-volume-related cost drivers. To incorporate the non-volume-related drivers, we can model the costs as functions of the relevant activity driver, as shown in chapter 7. Let $a_j = \sum_i a_{ji}$ be the total amount of activity *j* driver used for the period (where a_{ji} is the amount of resource *j* driver consumed by product *i*) and m_{ji} be the capacity of activity *j* for product *i* in terms of activity driver a_j. Then the fixed cost of activity *j* is given by

$$F_{Aj} = k_j \left\lceil \sum_i \frac{a_{ji}}{m_{ji}} \right\rceil$$

and the fixed cost allocated to product *i* from activity *j* is given by

$$F_{Aji} = k_j \left\lceil \sum_i \frac{a_{ji}}{m_{ji}} \right\rceil \left({}^{a_{ji}}\!\big/_{a_j} \right)$$

where k_j is the cost of a given capacity for activity j. The break-even quantities are given by

$$BE(\$) = \sum_i \left[\frac{\sum_j k_j \left[\sum_i \frac{a_{ji}}{m_{ji}} \right] \left({}^{a_{ji}}\!/\!_{a_j} \right)}{\left(1 - {}^{V_i}\!/\!_{P_i} \right)} \right]$$

and

$$BE(x_i) = \frac{\sum_j k_j \left[\sum_i \frac{a_{ji}}{m_{ji}} \right] \left({}^{a_{ji}}\!/\!_{a_j} \right)}{(P_i - V_i)}$$

Conclusion

Obviously the fixed and variable costs used in the break-even model depend on the information provided by the accounting system. If the accounting system allocates only variable production costs to each product based strictly on one cost driver such as production volume, then the information needed for a traditional break-even analysis can be easily obtained, although the product cost and contribution margins might be highly distorted. In addition, the traditional model arbitrarily assigns fixed costs to products based on sales volume or sales mix. ABC, on the other hand, allocates both fixed and variable costs to products using a number of different cost drivers. This provides us not only with more accurate product costs (and therefore more accurate contribution margins) but it also gives us a more rational basis for the determination of the break-even point.

By using the most appropriate cost drivers, ABC allocates costs more accurately. This allows us to model costs based on the capacity of an activity to handle any cost driver, not just volume. We can use this information to revise the break-even model to allow for step function costs that depend on these drivers, enabling us to incorporate the long-term variability with respect to capacity and create a more realistic model. ABC can not only change the parameter values of the break-even model (revised value for F_i) but may also change the model assumptions (fixed costs are allocated based on activity usage rather than sales volume) and even the model itself (driver-based step functions).

CHAPTER 9
CONCLUSION AND FURTHER RESEARCH

Conclusion

ABC was originally designed to more accurately determine product cost, but it has grown to encompass all areas of cost accounting with the development of activity-based management. As a result, researchers are motivated to study not only the cost implications of this new method of accounting, but also how the ABC methodology influences decisions. With this in mind, we explored several areas of operations research that can be affected by activity-based costing.

The primary focus of our study was not to develop new mathematical procedures to solve these problems but to explore how these models change when subjected to the ABC methodology and to formulate new models that take advantage of the detailed information provided by ABC. As a result of these studies we found several areas that can be changed by ABC: the value of cost parameters, the treatment of indirect costs both in the objective function and the constraints and, in some cases, the overall structure of the problem.

Cost Parameters

The most obvious way in which ABC can change a decision model is to alter the value of the cost parameters. Without changing the model formulation, ABC will still likely provide significantly different values for the cost parameters used in the model. We saw examples of this in the EOQ model, where the setup cost and inventory cost provided by the accounting system could differ significantly under ABC and traditional cost accounting. The same observation was made for the cost of activities in the cost/schedule model and the marginal cost of products in the product mix and break-even models.

Indirect Costs

Possibly the most significant effect of ABC on decision models is the treatment of indirect costs. This is not surprising, since traditional operations research models are based on traditional cost methods which offer a simple but inaccurate accounting of indirect costs. As a result, the models were limited not only by the information available from the accounting system, but also by the simplistic treatment of indirect costs.

Some models, such as the EOQ model and the marginal cost formulation of product mix, completely ignored indirect fixed costs as irrelevant to the decision. Scheduling models typically do not even include cost in the formulation, relying instead on implied cost savings to justify the objective function. Others models, such as the cost/schedule model and the break-even model, lumped all non-volume-related costs into a single "fixed" parameter that played a secondary role in the decision making process. This proved to be very fertile area of research. By incorporating the detailed indirect cost information provided by ABC into the traditional operations research models, we were able to improve both the objective functions and constraints, creating more realistic models.

Problem Structure

In some cases, such as scheduling models, ABC enabled us to propose new models. This is an example of how the ABC methodology provided a different focus for a traditional operations research area, thereby allowing us to explore alternative optimization goals. The break-even problem was affected in a similar way. Rather than just optimizing schedules based on direct costs, activity-based costing allowed us to optimize schedules based on both direct and traceable indirect costs, significantly changing the results of the model.

In other cases, the ABC methodology changed the entire problem solving process. This is the effect it had on investment analysis, where the tracing of cost savings using the ABC-defined activities and drivers allowed us to improve our comparison of investment alternatives. ABC also allowed us to tie performance to activities, thereby providing an tangible link from investment dollars to performance, an area that is often regarded as subjective.

Further Research

Obviously we have not covered all the operations research models possible, nor have we even looked at all the different types of problems available in this diverse field of study. We have, however, illustrated how ABC can effect decision models and outlined the basic areas where ABC is most likely to have an impact: the value of cost parameters, the modeling of indirect or fixed costs and possibly the problem structure. In the following sections, we discuss some other areas of operations research that might benefit from the insights provided by activity-based costing.

Location Models

Location models seek to find the optimal location for one or more facilities within a given set of constraints. Although planar location models focus on distance-related costs (the objective is to minimize a weighted distance function), there are certainly other costs involved, such as purchase, construction, maintenance and operation when considering the location of a new facility. Francis et al. (1992) note that perhaps the strongest criticism of planar location models may be the fact that they ignore these costs, an assumption that can be justified only if they will be approximately equal from site to site. If this assumption is not valid, then a mixed-integer programming model would be more appropriate, where the objective function might be

$$\text{Min } \sum_{i\in I}\sum_{j\in J} c_{ij}x_{ij} + \sum_{i\in I} f_i y_i$$

where c_{ij} is the transportation cost per unit, x_{ij} is the number of units shipped between locations i and j, f_i is the fixed cost for location i and y_i is 1 if location i is chosen and 0 otherwise. In this model we must select from a given set of locations, where the cost per mile is imbedded in the transportation cost, c_{ij}. The cost parameters (such as cost per mile) used in the decision model will be based on past costs derived from the accounting system. For example, operation, maintenance and transportation costs for similar facilities and locations will all be extracted from the accounting records. Due to differences in overhead allocation, the values of these parameters might be significantly different depending on whether the cost records are based on traditional cost accounting or ABC.

There are other costs however, that do not vary on a per unit basis but are not necessarily fixed. For example, the salary of warehouse personnel would only be fixed over a certain range of units, or there might be storage costs that are more dependent on complexity (say the number of different products assigned to a warehouse or the amount of handling required by different types of products) or special equipment costs that should be allocated only to those products that require that equipment. If an ABC analysis shows that these other costs are significant, then the objective function must be modified to incorporate them. For example, if fixed costs are only valid over a certain range of capacity, we will have to use f_{ik} for each range k. We could solve the mixed-integer problem for each range k, then find the optimal solution from among each of these results. If our ABC analysis shows that a cost driver other than number of units x is significant, say z, then we could incorporate this into our model as follows:

$$\text{Min} \sum_{i \in I} \sum_{j \in J} c_{ij} x_{ij} + \sum_{i \in I} (f_i + h_i z_i) y_i$$

where h_i is the portion of location *i* costs that vary with cost driver z_i.

Alternatively, we could incorporate all the possible fixed costs by using a function of activity drivers as we have done in previous chapters. Let the fixed cost for each activity *h* be

$$k_h \left\lceil \frac{a_h}{m_h} \right\rceil$$

where k_h is the fixed cost of a given capacity for activity *h*, a_h is the total amount of activity *h* driver used and m_h is the capacity of activity *h* in terms of driver *a*. To obtain the total fixed cost assigned to location *i*, we sum all the activities at each location

$$\sum_h k_h \left\lceil \frac{a_h}{m_h} \right\rceil$$

Then we can formulate the location problem as follows

$$\text{Min} \sum_{i \in I} \sum_{j \in J} c_{ij} x_{ij} + \sum_{i \in I} \sum_{h \in H} k_h \left\lceil \frac{a_h}{m_h} \right\rceil y_i$$

The significant contribution of ABC to the location model lies not only in the value assigned to the traditional cost parameters (c_{ij} and f_i), but also in the fact that other cost drivers may be identified as significant to the decision. ABC will do this not only because these cost drivers have been identified for similar locations in the past, but also because when the company opens the new locations and starts tracking costs, the ABC system will allocate costs using these drivers. If the analysis has been performed without taking these cost drivers into consideration, management may be surprised by the actual expenses.

Because location problems are usually one-time decisions involving large expenditures that require careful evaluation of all the alternatives, it is unlikely that any real world location decision will be made without consideration of all the cost drivers involved with each alternative, not just number of units. In fact, the process of determining the relevant costs for location alternatives will be very similar to an ABC analysis: the decision maker will determine what activities are to be performed at each of the possible new locations and how much resources these activities will consume. Of course if an ABC system is already in place, this information may be much easier to gather. Either way, all the relevant costs are gathered at the activity level and it is likely that the allocation of overhead to activities will be similar to the allocation made by an ABC system, if a careful analysis of the cost drivers is made.

Network Models

Network models seek to find the optimal routing given certain supply and demand requirements and a number of possible routes. The objective function assumes that the cost driver is the number of units transported, x_{ij}:

$$\text{Min} \sum_{i \in I} \sum_{j \in J} c_{ij} x_{ij}$$

These decisions may be made on a day-to-day basis with the parameter values changing as demand and transportation costs change. For this reason, the models used are relatively simple and do not involve extensive cost studies prior to each decision. Thus, while demand may change on a daily basis, it is likely that the cost parameters, c_{ij}, are updated less frequently, perhaps yearly or every six months. These "standard" values will be derived from the information provided in the accounting system. For example, the cost per unit can be compiled from the fuel, maintenance, depreciation and labor expenses associated with transportation by summing these amounts and dividing by the number of units transported in a period of time.

As we have observed previously, limiting our model to one cost driver may not provide a reasonable approximation of the actual expenses. This is where an ABC analysis may reveal that certain activities involved in transporting units from one location to another may consume resources based on other cost drivers. At the very least there may be certain costs that do not vary with the number of units but rather are fixed from shipment to shipment. This would be a more realistic assumption, where there is a maximum number of units that can be shipped at one time, so that there are certain batch related costs associated with transportation. In this case we would need to revise our objective function to include this new cost driver:

$$\text{Min} \sum_{i \in I} \sum_{j \in J} (c_{ij} x_{ij} + b_{ij} y_{ij})$$

where b_{ij} is the fixed cost per shipment and y_{ij} is the number of shipments made from location i to location j. In addition to the usual constraints associated with network problems, we would have a limit on the batch size, say B and the requirement that $By_{ij} \geq x_{ij}$.

The important thing to note is that once again ABC has not only offered the possibility of changing the value of the cost parameters, c_{ij}, but it may also lead to a different decision model. The insight provided by focusing on activities rather than products allows decision makers to make more realistic assumptions in their models. ABC will help determine whether or not a revised model is necessary by examining the transportation process and identifying activities and cost drivers. ABC can also provide an incentive to consider previously ignored cost drivers by allocating costs based on these drivers, which in turn motivates managers to find ways of controlling these cost drivers.

Other Areas

Some other areas that might benefit from the insights provided by ABC include quality models, specifically the cost of quality, dynamic lot size models, stochastic scheduling models and cost models in queuing theory. But in addition to examining how ABC can affect decision models, which is the focus of this study, we could also look at how operations research methods can influence activity-based costing. For example, ABC uses standard rates when allocating indirect costs. These standard rates are average values based on past performance. It would be interesting to explore the effect of variance and covariance on ABC cost drivers and how they might be controlled. Another area of interest would be forecasting and how we can use forecasting methods to derive better cost drivers and rates for the ABC system.

Modeling the results of ABC on future operations is another topic of interest. This could be investigated using simulation (see Needy and Malzahn, 1993) and forecasting, as well as sensitivity analysis. A number of operations research techniques can also be used to model the behavior of an ABC system, such as AHP (as was done by Partovi, 1991) or the Markov process. This area of study would be particularly useful in the application of ABC to real world situations.

As we have seen, ABC can influence a variety of operations research areas because it alters the way in which we view costs. This can affect both the models that rely on the costs provided by the accounting system and how we look at the business process. Although the study of ABC has been limited in large part to the accounting field, its impact on other fields of research is obvious and deserves our continued attention.

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BIOGRAPHICAL SKETCH

Diana Isaza Angelis was born in Cali, Colombia and moved to the United States when she was eleven years old. She received her degree in accounting from the University of Florida in 1977, then worked as an auditor for the State of Florida. She returned to the University of Florida in 1982 to study electrical engineering and received her B.S.E.E. in 1985. She was commissioned an officer in the United States Air Force in 1984 and served on active duty as a program engineer until 1989. In 1992 she began studying engineering management in the Department of Industrial and Systems Engineering at the University of Florida. After graduation, Ms. Angelis will be teaching at the Defense Resources Management Institute of the Naval Postgraduate School, in Monterey, California. Ms. Angelis is a Certified Public Accountant and a Captain in the US Air Force Reserve. She and her husband Jim have two daughters, Alix and Kris.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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